PRESIDENCY UNIVERSITY

DEPARTMENT OF LIFE SCIENCES

PhD Thesis Synopsis

Sustainable Water Resource Management of Agriculture in India

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R-14RS18110012

(6th May, 2016)

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TITILE OF THE THESIS: **Sustainable Water Resource Management of Agriculture in India**

PhD REGISTRATION NUMBER: R-14RS18110012 (6th May, 2016)

ENROLMENT NUMBER: SC/DOC/13-14/163

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Abbreviations

- AWW - Agricultural water withdrawal,
- BAU – Business-as-usual,
- BC - Black carbon,
- BDWS - Basic drinking water services,
- BSS - Basic sanitation services,
- CO - Carbon monoxide,
- CPI - Corruption Perceptions Index,
- DC - Dam capacity,
- EF - Ecological footprint,
- GFN - Global Footprint Network,
- GHG – Greenhouse gases,
- ISF - Improved sanitation facilities,
- IWS - Improved water source,
- IWW - Industrial water withdrawal,
- MF - Material footprint,
- MWW - Municipal water withdrawal,
- NAHF – No access to handwashing facilities
- NH_3 - Ammonia
- NMVOC - Non-methane volatile organic compounds,
- NOx - Oxides of nitrogen,
- NTMWW - Not treated municipal wastewater,
- OC - Organic carbon,
- OD - Open defecation,
- PB – Planetary boundaries,
- PM_{10} - Particulate matter 10,
- $PM_{2.5}$ bio - Particulate matter 2.5, of biological origin,
- $PM_{2.5}$ fossil - Particulate matter 2.5, of fossil fuel origin,
- PMWW - Produced municipal wastewater,
- PS - poor sanitation,
- SMDWS - Safely managed drinking water services,
- SO_2 - Sulphur dioxide,
- TIRWR - Total internal renewable water resources,
- TMWW - Treated municipal wastewater,
- TRWR - Total renewable water resources,
- TWW - Total water withdrawal,
- UWS – Unsafe water source,
- VAI - Voice & Accountability Index,
- WF – Water footprint,
- WS - Water stress,
- WUE - Water use efficiency,

Abstract:

Agriculture (with industry and household sector) is one of three major sectors of human consumption in this Anthropocene era. For assessment of sustainability of agricultural water resource consumption, various methods have been used to get insight into this dimension from multiple perspectives, such as - triple bottom line approach, planetary boundaries framework, doughnut economy etc. At the end, agricultural indicators have been calibrated with UN SDGs (2030). To exert priority on India (i.e. operational boundary), every analysis has been done in the level of national - scale.

Introduction:

Agriculture intermingles with earth system processes through numerous pathways (viz. GHG emissions, excessive water use, land-use change, and biodiversity impacts). It is also a chief driver of climate change (1, 2, 3, 4), freshwater resources depletion (5), change of land-use system (6, 7, 8), biogeochemical flows of nitrogen (9, 10, 11, 12) and phosphorus (13, 14) (through fertilizer and manure application), loss of biodiversity (15, 16), emission of atmospheric pollutants etc. Among the biophysical resources that agriculture consumes, water has got the highest priority due to contemporary scenario water scarcity and agroeconomic nature of the nation (India). Thus, assessment water resource consumption in agricultural sector for moving towards sustainable development while feeding a billion people is one of the major problems that India faces now.

Objectives:

1. To estimate water use in all major agricultural and agriculture-derived products in India (1970s to present).
2. Bayesian probabilistic projection of future water use in all major agricultural and agriculture-derived products in India (present – 2100).
3. Effect of international trade (both import and export) of all major agricultural and agriculture-derived products on sustainable utilization of water resources in Indian agriculture (1960s to present).
4. Understanding effects of population growth (from past i.e., 1950, present and to future i.e., 2100) on agricultural sustainability (of water resources) in India.
5. To understand the effects of climate change on agricultural production in India.
6. To suggest changes or alterations in form of replacements to make agriculture more water-efficient.

Chapter 1

'Safe and Just Operating Space' in India

Methodology:

a. *Biophysical Consumption Indicators*:

Though present study mostly followed 17 and 18 approach of planetary boundaries framework, we have adjusted all of the indicators and boundaries to ensemble national scale and circumstances of India (Table 1). This study used 5 indicators as per updated planetary boundaries framework of 18 (climate change, nitrogen flow, phosphorus flow, land-system change and freshwater use) and 2 of 19 (EF & MF).

Table 1: Dimensions and indicators of the ecological ceiling (Planetary boundaries concept) for India (Objective 1, 3).

Dimensions (related SDGs)	Indicators	Boundary (global, average, per capita)	Data Sources
Climate change (SDG 13)	GHG emissions including Land-Use Change and Forestry (t CO_2-e) Per Capita Per Year (1990-2014)	5.75t CO_2-e $year^{-1}$ (2014)	CAIT
Freshwater use (SDG 6)	Total water withdrawal (m^3) Per Capita Per Year (1973-2012)	574.86m^3 $year^{-1}$ (2010)	Aquastat
Arable land use (SDG 15)	Agricultural land area (ha) Per Capita Per Year (1961-2015)	0.27ha $year^{-1}$ (2015)	FAOSTAT, WDI
Nitrogen use (SDG 14)	Nutrient nitrogen N use (kg) Per Capita Per Year (2002-2015)	8.4kg N $year^{-1}$ (2015)	FAOSTAT
Phosphorus use (SDG 14)	Nutrient phosphate P_2O_5 (kg) Per Capita Per Year (2002-2015)	0.84kg P $year^{-1}$(2015)	
Ecological footprint (SDG 14, 15)	Ecological footprint (gha) Per Capita Per Year (1961-2013)	1.66gha $year^{-1}$ (2013)	GFN
Material footprint (SDG 12)	Material footprint (t) Per Capita Per Year (2000-2010)	7.18t $year^{-1}$ (2010)	UNData (UNSD)

b. *Social Development Indicators*:

For this part of the work, the doughnut economics framework of 20, 21 have been followed (Table 2).

Table 2: Dimensions and indicators of social foundation (Safe and Just space, SJS of Doughnut economy concept) for India. (Objective 1, 3)

Dimensions (related SDGs)	Indicators	Thresholds	Current Status	Data Sources

Education (SDG 4)	Primary school age children out of school (1970-2015)	≤10% children	2.26% (2013)	WDI
	Adult literacy rate (ages ≥15 years) (1970-2016)	≥90% people	69.3% (2012)	
	Secondary school enrolment (1970-2015)		73.97% (2015)	
Energy (SDG 7)	Electricity access (1990-2014)		79.17% (2014)	
	Clean fuels and technologies for cooking access (2000-2014)		34.16% (2014)	
Food (SDG 2)	Average calorific intake of food & drink (kcal/capita/day) (1961-2013)	≥2700 calories	2459 (2013)	FAOSTAT
	Undernourishment rate (2000-2015)	≤5% people	14.5% (2015)	WDI
Gender Equality (SDG 5)	Women in national parliaments (1997-2017)	50% of seats held by women in national parliaments	11.8% (2017)	
Health (SDG 3)	Life expectancy at birth (1960-2015)	≥70 years at birth	68.33y (2015)	
	Mortality rate (1960-2016)	≥25 per 1000 births	43 (2016)	
Housing (SDG 11)	Urban slum living population (1990-2014)	≤10% people	24% (2014)	
Income (SDG 1) & Work (SDG 8)	Poverty headcount ratio (1981-2015)	≤5% people	21.2% (2011)	
	Youth unemployment (1991-2017)	≥94% employment	10.2% (2017)	
Networks (SDG 9.c)	Internet use (1990-2016)	≥90% people	29.55% (2016)	WDI
Peace & Justice (SDG 16)	CPI (1995-2015)	Score ≤5 out of 10 in CPI (up to 2011), Score ≤50 out of 100 in CPI (from 2012 onwards)	38 (2015)	TI
	Intentional homicides rate (1995-2015)	≤100	3.2 (2014)	WDI
Political Voice (SDG 16.7)	VAI (1996-2016)	Score ≤0.5 out of 1.0 in VAI	0.41 (2013)	WGI
Social Equity (SDG 10)	Gini index (1960-2015)	70 on (0–100) scale on Gini index of 0.30	35.15 (2011)	WIID3.4
Water & Sanitation (SDG 6)	ISF (1990-2015)	≥90% people	39.6% (2015)	WDI
	IWS (1990-2015)		94.1% (2015)	

c. *Future scenario*:

To project probable future scenario of total biophysical consumption, future (2015-2050) population projection (median range prediction value of 50%) of India is to be integrated with per capita consumption of each dimension of PBs. 3 projection series for each dimension of PBs has also been calculated that are based on - (1) lowest consumption value, (2) highest consumption value and (3) BAU scenario.

Results:

(a) *Biophysical Consumption Indicators*:

It is clear from the Table 3 and Figure 1, that India has already crossed 3 of 7 dimensions of per capita biophysical boundaries (freshwater, nitrogen and phosphorus use). 3 PBs have exceeded their boundaries by 4.5% (freshwater use), 40.3% (nitrogen use) and 85.1% (phosphorus use). Remaining 4 PBs are within 42.9% (climate change), 51.85% (arable land use), 36.1% (ecological footprint) and 50.5% (material footprint) of exceeding their boundaries.

Table 3: Present state and future prospects of 7 biophysical consumption indicators for India. (Objective 1, 3)

Indicators	**Current Status**	**Change** (+ increase, - decrease)	**Since (Year)**	**Boundary crossing time (BAU)**
GHG emission	2.47 t CO2-e (2014)	+46.95%	1990	2045-2047
Freshwater withdrawal	602.3 m^3 (2010)	+3.07%	1973	2007-2008
Arable land use	0.13 ha (2015)	-64.61%	1961	2035
Nitrogen use	14.07 kg N (2015)	+27.51%	2002	2002
Phosphorus use	5.65 kg P (2015)	+30.54%	2002	Before 2002
EF	1.06 gha (2013)	+43.87%	1961	2020-2025
MF	3.56 t (2010)	+30.61%	2000	2025-2030

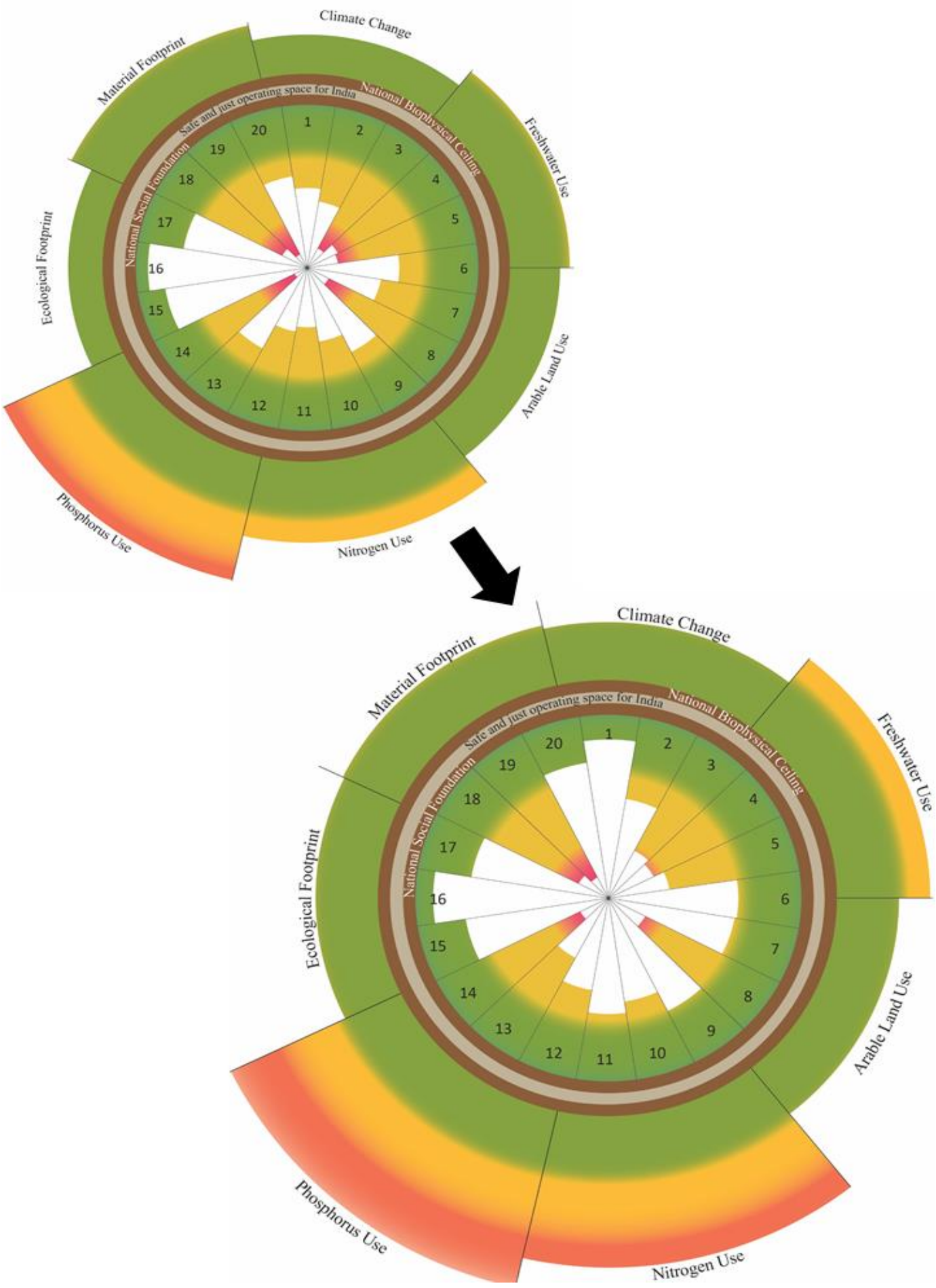
Climate Change
Freshwater Use
Arable Land Use
Nitrogen Use
Phosphorus Use
Ecological Footprint
Material Footprint
Safe and just operating space for India
National Biophysical Ceiling
National Social Foundation
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Fig 1. Trends in national barometer for sustainable development in India. (Objective 1, 3)
Here, the 7 national dimensions of biophysical stress established over national biophysical ceiling outwardly projected. Also, 20 indicators composing 12 dimensions of social deprivation established under national social foundation inwardly projected for India. Left and Right represent the status of sustainable development of India in 2000 and 2011 respectively. 12 dimensions of the social foundation are education 1-3, energy 4-5, food 6-7, gender equality 8, health 9-10, housing 11, income and work 12-13, networks 14, peace and justice 15-16, political voice 17, social equity 18, water and sanitation 19-20.
[Colour scheme: Green = safe operating space for biophysical indicators and thresholds for indicators of social development; Yellow = zone of increasing impact for biophysical indicators and zone of increasing deprivation for indicators of social development; Red = zone of high risk of serious impact for biophysical indicators and zone of the high level of deprivation for indicators of social development; Outer chocolate ring = National biophysical ceiling; Inner chocolate ring = National social foundation; The area between the chocolate rings = the safe and just operating space for sustainable development in India]

(b) ***Social Development Indicators*****:**

In India, primary school age children out of school, undernourished population, mortality rate, urban slum living population, poverty headcount ratio, intentional homicides, VAI score have decreased 36.42% (from 1970), 2.7% (from 2000), 82.49% (from 1960), 30.9% (from 1990), 32.7% (from 1981), 26.71% (from 1995) and 12.76% (from 1996), respectively. On the other hand, adult literacy rate, secondary school enrolment, access to electricity, access to clean fuels and technologies for cooking, average calorific intake of food and drink, women in national parliament, life expectancy, youth unemployment, internet use, social equity, ISF and IWS have increased 28.53% (from 1970), 49.94% (from 1970), 31.1% (from 1990), 9.69% (from 2000), 18.25% (from 1961), 4.6% (from 1997), 39.75% (from 1960), 1.2% (from 1991), 29.55% (from 1990), 7.25% (from 1960), 22.8% (from 1990) and 23.6% (from 1990), respectively. For the 12 dimensions of SJS framework, only one (peace and justice) has been non-deprived. Of 20 indicators that we analysed for India, only 5 were not socially deprived, which are – children out of school, CPI, intentional homicide rate, 'VAI' and 'IWS'. However, among the rest 15 indicators, only 1 is getting more distant from the threshold, namely youth unemployment; all the remaining 14 indicators were coming are closing in towards their respective thresholds. 5 of the 14 indicators are showing much improvement over the years (secondary school enrolment, access to electricity, life expectancy, mortality rate and urban slum living population) and in a BAU scenario, they might reach their thresholds within a few years. Most deprivation exists for eight dimensions - energy, gender equality, income and work,

networks, peace and justice, political voice, social equity, water and sanitation. Least deprivation exists for three dimensions – education, health, and housing. The results related to social development indicators (doughnut economy) are shown in table 4 and figure 2a-2c.

Table 4: Changes and future prospects of 20 social development indicators for India. (Objective 1, 3)

Indicators	**Change since initial year** (+ increase, - decrease)	**Since (Year)**	**Threshold meeting time** (BAU)
Primary school age children out of school	-36.42%	1970	2003-2004
Adult literacy rate	+28.53%	1970	2030-2035
Secondary school enrolment	+49.94%	1970	2030-2040
Electricity access	+31.1%	1990	2020-2025
Clean fuels and technologies for cooking access	+9.69%	2000	2090-2100
Average calorific intake of food & drink (kcal/capita/day)	+18.25%	1961	2030-2035
Undernourishment rate	-2.7%	2000	2035-2045
Proportion of seats held by women in national parliaments (%)	+4.6%	1997	Not before 2100
Life expectancy at birth	+39.75%	1960	2020-2025
Mortality rate	-82.49%	1960	2015-2020
Urban slum living population	-30.9%	1990	2020-2025
Poverty headcount ratio	-32.7%	1981	2030-2040
Youth unemployment	+1.2%	1991	Not before 2100
Internet use	+29.55%	1990	2090-2100
CPI	NA	1995	Not before 2100
Intentional homicides	-26.71%	1995	Not before 2100
VAI	-12.76%	1996	Not before 2100
Gini index	+7.25%	1960	Not before 2100
ISF	+22.8%	1990	2065-2070
IWS	+23.6%	1990	2010

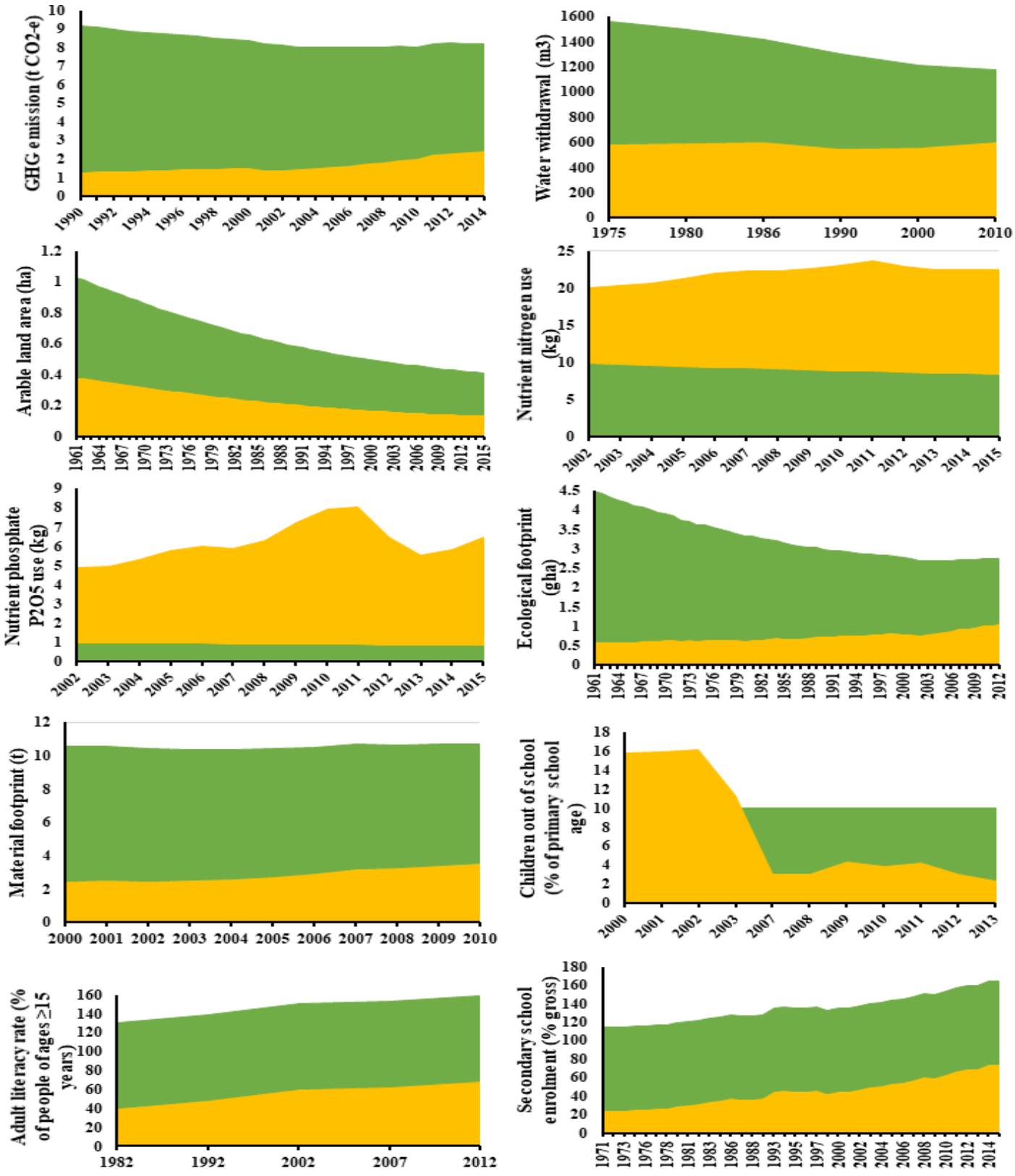

GHG emission (t CO2-e)
Water withdrawal (m3)
Arable land area (ha)
Nutrient nitrogen use (kg)
Nutrient phosphate P2O5 use (kg)
Ecological footprint (gha)
Material footprint (t)
Children out of school (% of primary school age)
Adult literacy rate (% of people of ages ≥15 years)
Secondary school enrolment (% gross)

Fig 2a. Changes in per capita biophysical indicators and indicators of social development of sustainable development in India with time. (Objective 1, 3) [Colour scheme: Green = global per capita boundaries for biophysical indicators and thresholds for indicators of social development; Yellow = values of indicators for India.]

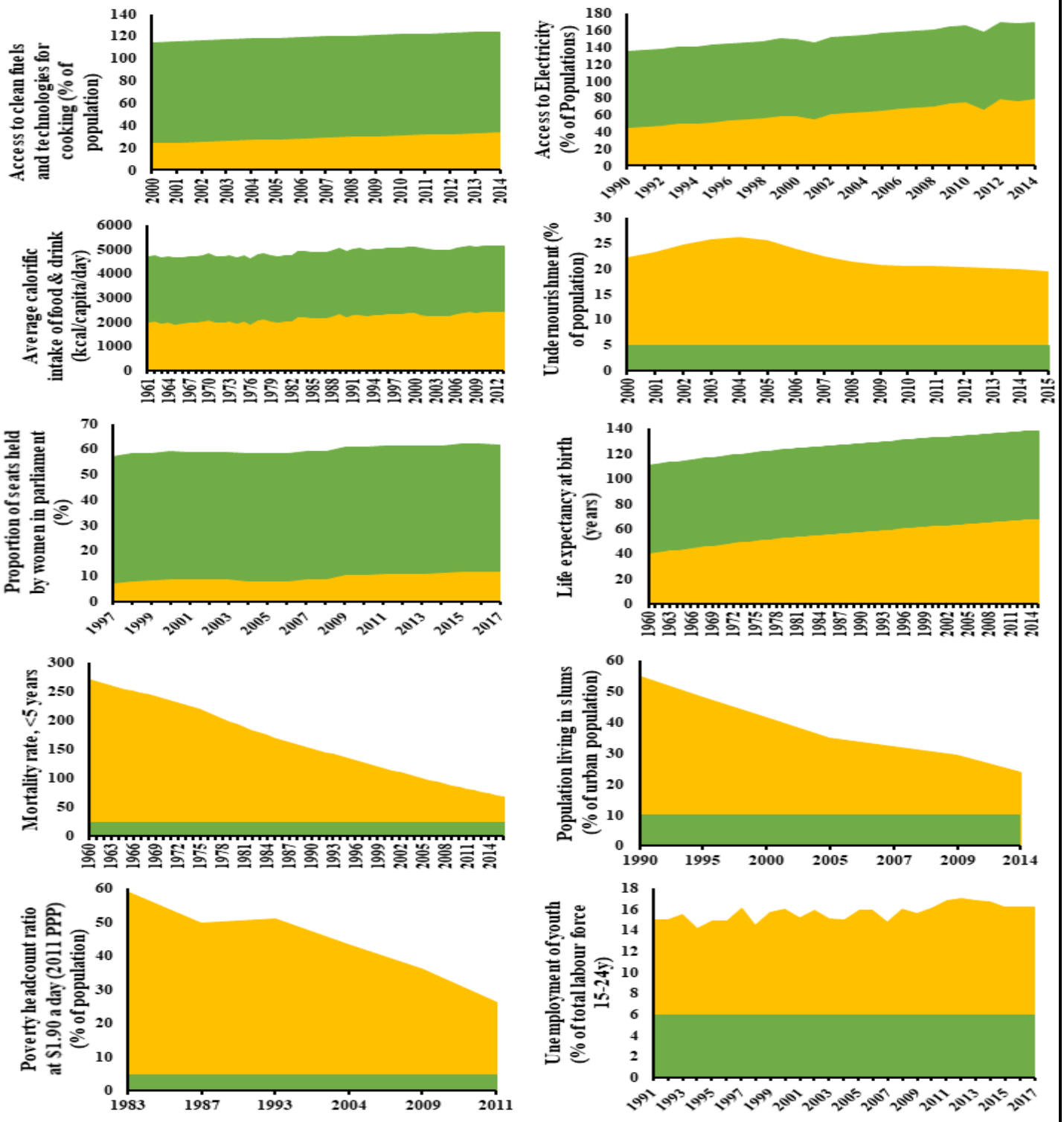

Access to clean fuels and technologies for cooking (% of population)
Access to Electricity (% of Populations)
Average calorific intake of food & drink (kcal/capita/day)
Undernourishment (% of population)
Proportion of seats held by women in parliament (%)
Life expectancy at birth (years)
Mortality rate, <5 years
Population living in slums (% of urban population)
Poverty headcount ratio at $1.90 a day (2011 PPP) (% of population)
Unemployment of youth (% of total labour force 15-24y)

Fig 2b. Changes in per capita biophysical indicators and indicators of social development of sustainable development in India with time. (Objective 1, 3) [Colour scheme: Green = global per capita boundaries for biophysical indicators and thresholds for indicators of social development; Yellow = values of indicators for India.]

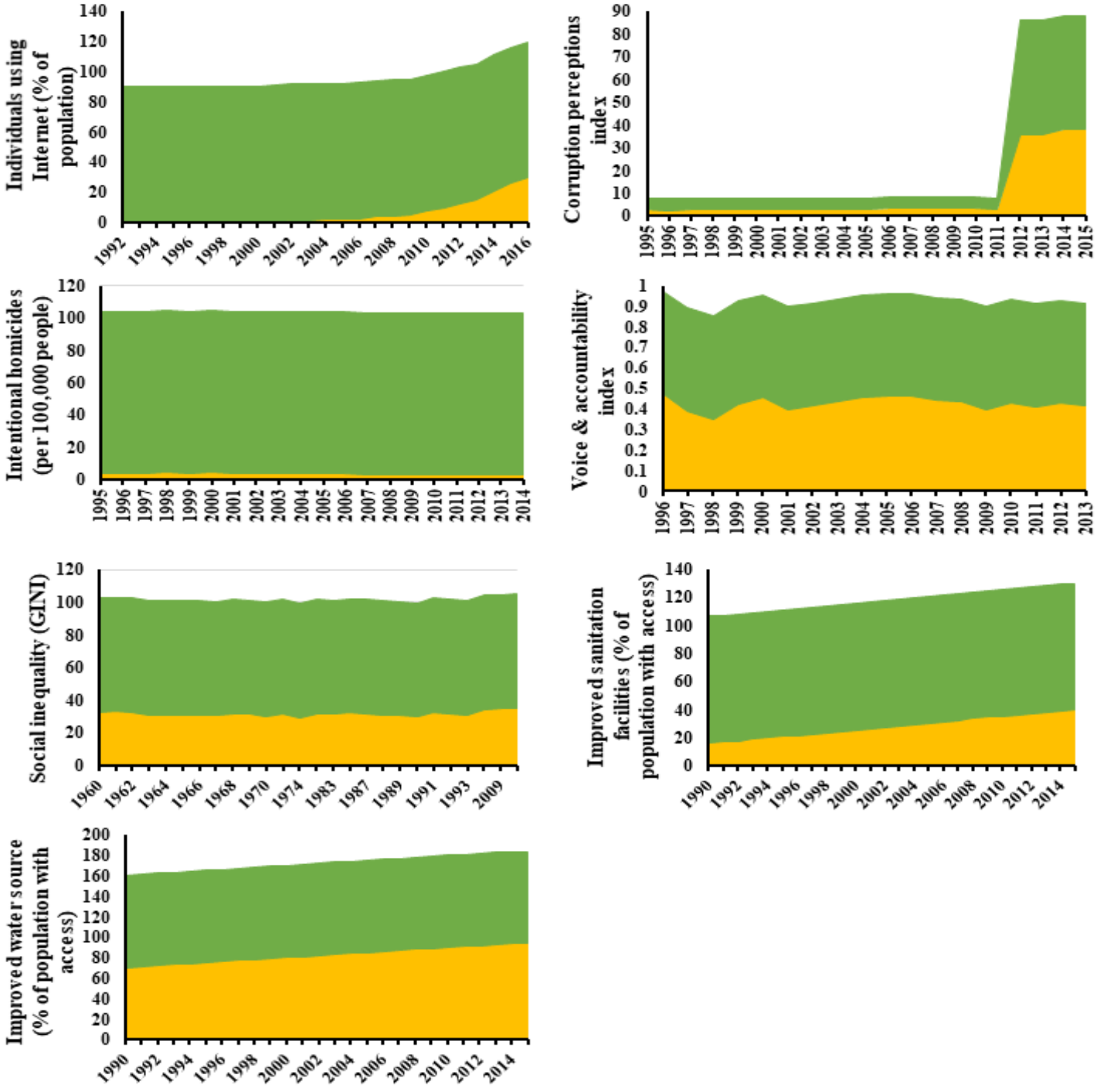

Individuals using Internet (% of population)
Corruption perceptions index
Intentional homicides (per 100,000 people)
Voice & accountability index
Social inequality (GINI)
Improved sanitation facilities (% of population with access)
Improved water source (% of population with access)

Fig 2c. Changes in per capita biophysical indicators and indicators of social development of sustainable development in India with time. (Objective 1, 3) [Colour scheme: Green = global per capita boundaries for biophysical indicators and thresholds for indicators of social development; Yellow = values of indicators for India.]

(c) ***A 'safe and just' India in 2050*:**

The results related to future changes (2050) in biophysical resource consumption are shown in table 5 and figure 3.

Table 5: Changes in biophysical resource consumption in India based on 3 scenarios in future (2050). (Objective 2, 4)

Indicators	**Change** (lowest rate, in 2050)	**Change** (BAU rate, in 2050)	**Change** (highest rate, in 2050)
GHG emission	-31.98%	+22%	
Freshwater use	+16.83%	+23.83%	+24.62%
Arable land use	+26.73%		+252.22%
Nitrogen use	-5.85%	+23%	+26.64%
Phosphorus use	-0.7%	+31.03%	+45.48%
EF	-27.8%	+22.93%	
MF	-6.49%	+25.79%	

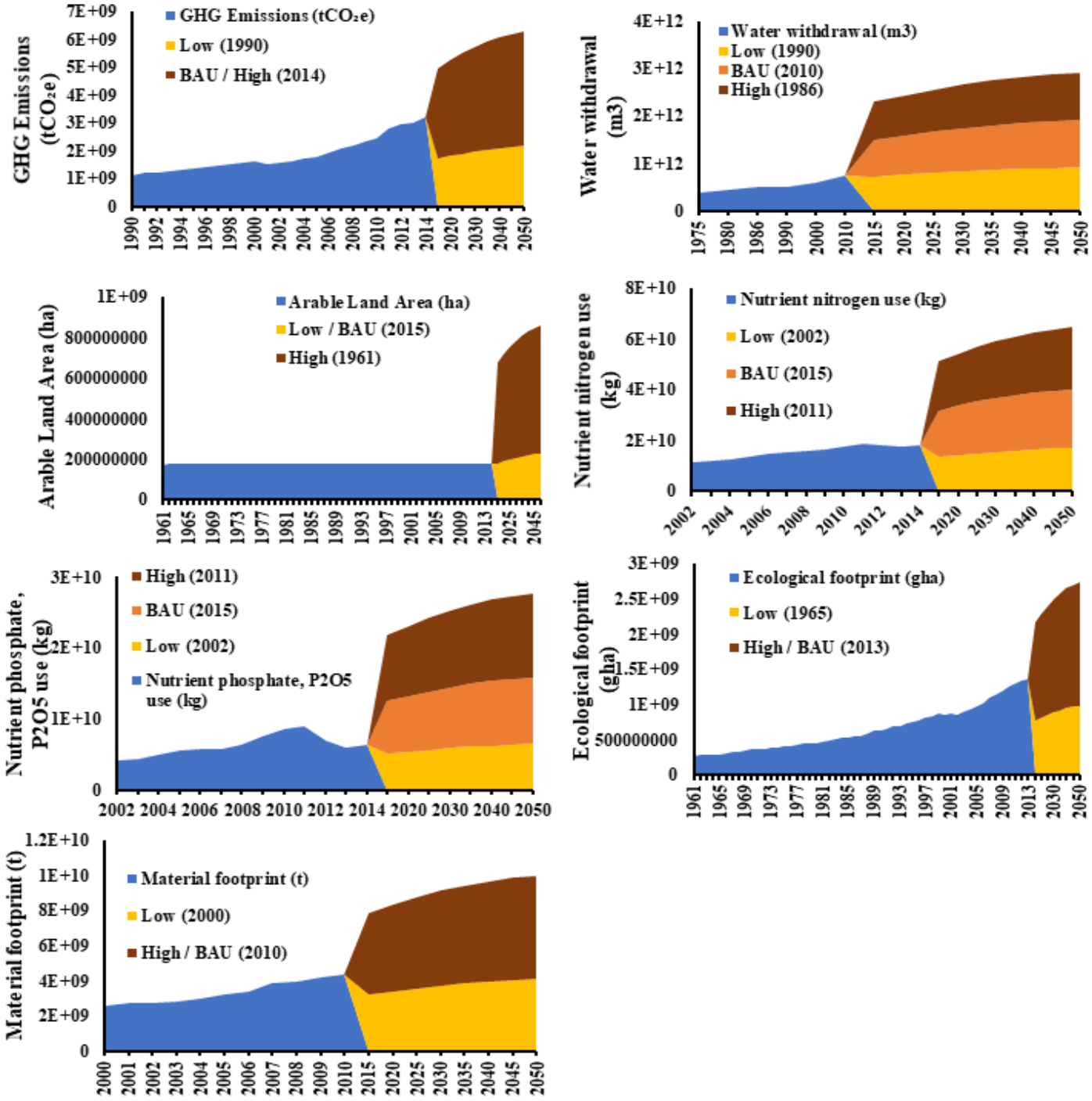


Fig 3. Future scenario of biophysical consumption in India up to 2050. (Objective 2, 4)

[Colour scheme: Blue = changes in total values of consumption of biophysical indicators; Brown = projected total values at highest rate of per capita consumption; Orange = projected total values at BAU rate of per capita consumption; Yellow = projected total values at lowest rate of per capita consumption.]

Table 6: **Regression Table**

	GHG emissions (t CO_2-e)	**Arable land area (ha)**	**Nutrient nitrogen N use (kg)**	**Nutrient phosphate P_2O_5 use (kg)**	**EF (gha)**	**MF (t)**
Primary school age children out of school	-16.03 ***	47.2 ***	-2.66 ***	-2.32 *	-72.51 ***	-12.31 ***
Adult literacy rate	16.65	-51.02 ***	1.83	4.64	64.14 **	2.25
Secondary school enrolment	25.94 ***	-54.39 ***	5.31 ***	4.46 *	100.82 ***	14.67 ***
Clean fuels and technologies for cooking access	7.9 ***	-44.81 ***	1.62 ***	1.41 **	27.17 ***	5.37 ***
Electricity access	26.18 ***	-81.83 ***	3.29 ***	2.62	89.53 ***	13.99 ***
Average calorific intake of food & drink	178.95 ***	-503.37 ***	49.05 ***	52.52 ***	1165.256 ***	129.87 ***
Undernourishment rate	-5.18 ***	24.88 ***	-1.54 ***	-1.59 ***	-18.36 ***	-3.68 ***
Women in national parliaments	3.26 ***	-13.96 ***	0.74 ***	0.78 **	10.89 ***	1.58 **
Life expectancy at birth	7.64 ***	-24.29 ***	1.02 ***	0.92 **	52.76 ***	3.16 ***
Mortality rate	-60.31 ***	191.99 ***	-7.94 ***	-7.1 **	-420.1 ***	-25.14 ***
Urban slum living population	-24.69 ***	76.02 ***	-4.5 *	-1.17	-99.61 ***	-11.25 **
Poverty headcount ratio	-25.52 **	49.35 ***	-4.27	-5.64	-72.69 ***	-8.76
Youth unemployment	1.68 ***	-4.29 ***	0.31 **	0.274	5.03 ***	0.21
Internet use	15.24 ***	-47.61 ***	3.5 ***	2.05	40.04 ***	4.87 ***
CPI	27.53 ***	-81.51 ***	5.34 *	-0.38	64.24 ***	0.71 ***
Intentional homicides	-0.97 ***	4.42 ***	-0.11 ***	-0.09 **	-3.54 ***	-0.68 ***
VAI	-0.007	-0.03	-0.004	-0.006	-0.02	-0.007
GINI Index	4.58 **	-2.27 **	0.29 ***	0.38	8.29 ***	0.74
ISF	18.11 ***	-57.02 ***	2.51 ***	2.19 **	61.29 ***	7.71 ***
IWS	18.07 ***	-57.31 ***	2.45 ***	2.16 **	61.5 ***	7.58 ***

Chapter 2

Sustainable development of Water & Sanitation (SDG 6) in India

Methodology:

The data related to SDG 6 of India has been categorized into 2 groups – biophysical (following planetary boundaries framework of 17; 18) (Table 7) and social development indicators (following doughnut economics framework of 20, 21) (Table 8).

(a) ***Biophysical Consumption Indicators:***

11 indicators (4 dimensions) have been analysed (figure 4).

Table 7. Biophysical consumption indicators related to sustainable development goal 6 (water and sanitation) for India. (Objective 1, 3)

Dimensions (related SDGs)	**Indicators (Year)**	**Safe Operating Limits**
Water withdrawal (SDG 6.1)	TWW (m^3) (1975-2010)	576.96 m^3 (2010)
	IWW (m^3) (1975-2010)	576.96 m^3 (2010)
	AWW (m^3) (1975-2010)	576.96 m^3 (2010)
	MWW (m^3) (1975-2010)	576.96 m^3 (2010)
Water availability (SDG 6.1)	TIRWR (m^3) (1962- 2014)	Boundary not yet available.
	TRWR (m^3) (1962- 2014)	
	DC (m^3) (1960-2005)	
Wastewater (SDG 6.3.1)	PMWW (m^3) (1979-2011)	
	TMWW (m^3) (1979-2011)	
	NTMWW (m^3) (1979-2011)	
Water Stress (SDG 6.4.2)	WS (%) (1979-2011)	

(b) ***Safe limit of freshwater use:***

Freshwater use PB is withdrawal of 4000 $km^3\ y^{-1}$ blue water (17). From this we have calculated per person average global level boundary of 576.96 $km^3\ y^{-1}$ (2010). We have also calculated the approximate time when safe operating limits were or will be crossed for biophysical consumption indicators (except - WUE).

(c) ***Social Development Indicators:***

We have analysed 17 indicators (Table 8) (figure 5).

Table 8. Social development indicators related to sustainable development goal 6 (water and sanitation) for India. (Objective 1, 3)

Dimensions (related SDGs)	**Indicators (Year)**	**Thresholds**	**Current Status**
OD (SDG 6.2.1)	OD (2000-2015)	≤10% people	39.83% (2015)
	OD, rural (2000-2015)		55.62% (2015)
	OD, urban (2000-2015)		7.41% (2015)
BDWS (SDG 6.1.1)	BDWS (2000-2015)	≥90% people	87.86% (2015)
	BDWS, rural (2000-2015)		84.98% (2015)
	BDWS, urban (2000-2015)		92.85% (2015)
BSS (SDG 6.2.1)	BSS (2000-2015)		44.15% (2015)

	BSS, rural (2000-2015)		33.8% (2015)
	BSS, urban (2000-2015)		65.4% (2015)
SMDWS (SDG 6.1.1)	SMDWS, rural (2000-2015)		49.47% (2015)
ISF (SDG 6.2.1)	ISF (1990-2015)		39.6% (2015)
	ISF, rural (1990-2015)		28.5% (2015)
	ISF, urban (1990-2015)		62.6% (2015)
IWS (SDG 6.1.1)	IWS (1990-2015)		94.1% (2015)
	IWS, rural (1990-2015)		92.6% (2015)
	IWS, urban (1990-2015)		97.1% (2015)
WUE (SDG 6.4.1)	WUE in agriculture (water withdrawal, m^3/ GDP, current US$) (1975-2010)	NA	2.2 m^3/ GDP, current US$ (2010)

(d) ***Just limit of freshwater access:***

We have also set a desirable threshold for social development indicators. We have also calculated the approximate time when desired thresholds were or will be met for social development indicators (except - WUE).

(e) ***Future scenario***:

To project future scenario of total consumption in water and sanitation, future (2015-2050) population projection (median range prediction value of 50%) of India is to be integrated with per capita consumption of each dimension of PBs. 3 projection series for each dimension of PBs has also been calculated that are based on - (1) lowest consumption value, (2) highest consumption value and (3) BAU scenario.

(f) ***Relationship of SDG 6 with SDG 3 and SDG 1:***

SDG 6-SDG 3:

To understand the relationship between SDG 6 and SDG 3, we have used 5 indicators.

No.	Indicators
1	child mortality rate (in acc. with OD)
2	prevalence of stunting (in acc. with ISF)
3	annual deaths from diarrhoeal diseases
4	death rate from diarrhoeal diseases
5	risk factor of water and sanitation related deaths

In risk factor of SDG 6 related deaths, 5 age groups (<5 years, 5-14y, 15-49y, 50-69y and 70y+) have been divided into 3 types, risk of deaths from (1) NAHF, (2) PS and (3) UWS.

SDG 6-SDG 1:

To understand the relationship between SDG 6 and SDG 1, 6 indicators have been used and their changes with respect to GDP have been observed. These are – (1) BDWS, (2) BSS, (3) ISF, (4) IWS, (5) OD and (6) SMDWS.

Results:

(a) *Biophysical Consumption Indicators:*

Among the 11 indicators of biophysical consumption of SDG 6, 4 have decreased and 7 have increased over time (Table 9). Current water stress level in India (44.53%) is almost 4 times more than average global level of water stress (12.82%) (Figure 4).

Table 9: Current status and changes of biophysical consumption indicators related to SDG 6 in India. (Objective 1, 3)

Indicators (Unit)	Current Status	Change since initial year (+ increase, - decrease)
TWW (m^3)	602.3 m^3 (2010)	+3.07%
IWW (m^3)	13.63 m^3 (2010)	-42.97%
AWW (m^3)	551.62 m^3 (2010)	-0.76%
MWW (m^3)	44.9 m^3 (2010)	+60.06%
TIRWR (m^3)	1103 m^3 (2014)	-64.29%
TRWR (m^3)	1458 m^3 (2014)	-64.29%
DC (m^3)	189.9 m^3 (2005)	+38.12%
PMWW (m^3)	12.23% (2011)	+64.68%
TMWW (m^3)	3.49% (2011)	+58.86%
NTMWW (m^3)	8.73% (2011)	+67.58%
WS (%)	44.53% (2011)	+18.4%

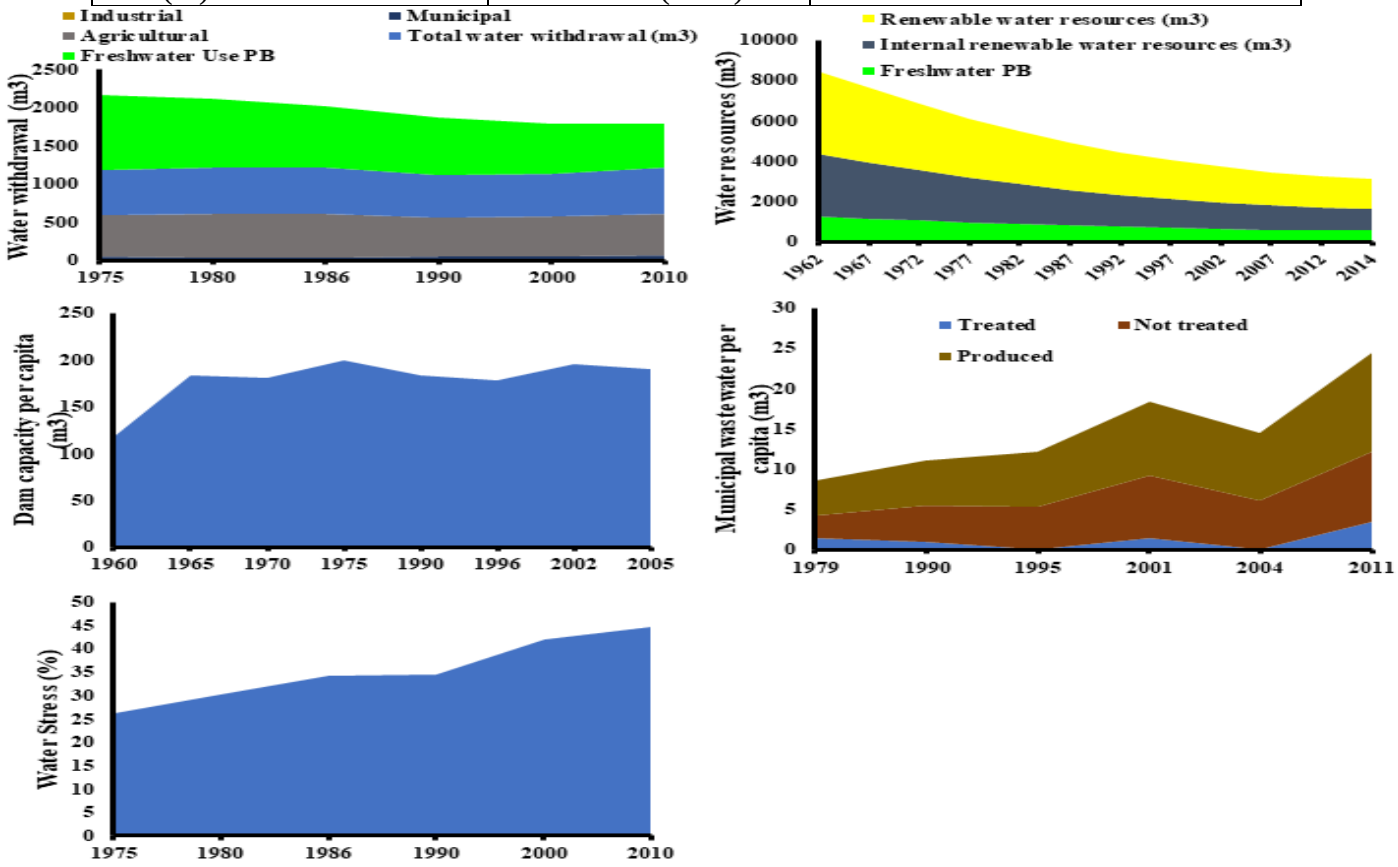


Fig 4. Trends of change in per capita biophysical indicators related to sustainable development goal 6 (water and sanitation) in India. (Objective 1, 3)

Green indicates global per capita safe limits for biophysical consumption indicators.

(b) ***Social Development Indicators:***

Table 10: Changes and threshold reaching time of social development indicators related to SDG 6 in India. (Objective 2, 4)

Indicators	**Change since initial year** **(+ increase, - decrease)**	**Threshold meeting time** **(BAU)**
OD	-26.14%	2030-2035
OD, rural	-26.59%	2035-2045
OD, urban	-16.08%	2013
BDWS	+7.15%	2020
BDWS, rural	+9.16%	2020-2025
BDWS, urban	+0.44%	Before 2000
BSS	+22.47%	2045
BSS, rural	+23.27%	2050-2055
BSS, urban	+14.59%	2040
SMDWS, rural	+20.19%	2045
ISF	+22.8%	2065-2070
ISF, rural	+22.9%	2075-2080
ISF, urban	+13.3%	2060-2065
IWS	+23.6%	2010
IWS, rural	+28.4%	2012
IWS, urban	+8.2%	1994
WUE in agriculture	-76.16%	NA

Among the 17 indicators of social development aspects of SDG 6, 4 have decreased and 13 have increased over time (Table 4). WUE in agriculture has also decreased significantly (76.16%) which is good, i.e. less amount of water is being withdrawn for the same amount of GDP. Immediate steps are needed to improve awareness and BSS. In India, among 16 indicators with desirable thresholds, 7 have either already met or going to meet SDG criteria within 2030, 1 indicator will reach the target just after 2030, and remaining 8, at current rate, will be able to meet in distant future (2040-2080), requiring immediate attention (Table 10).

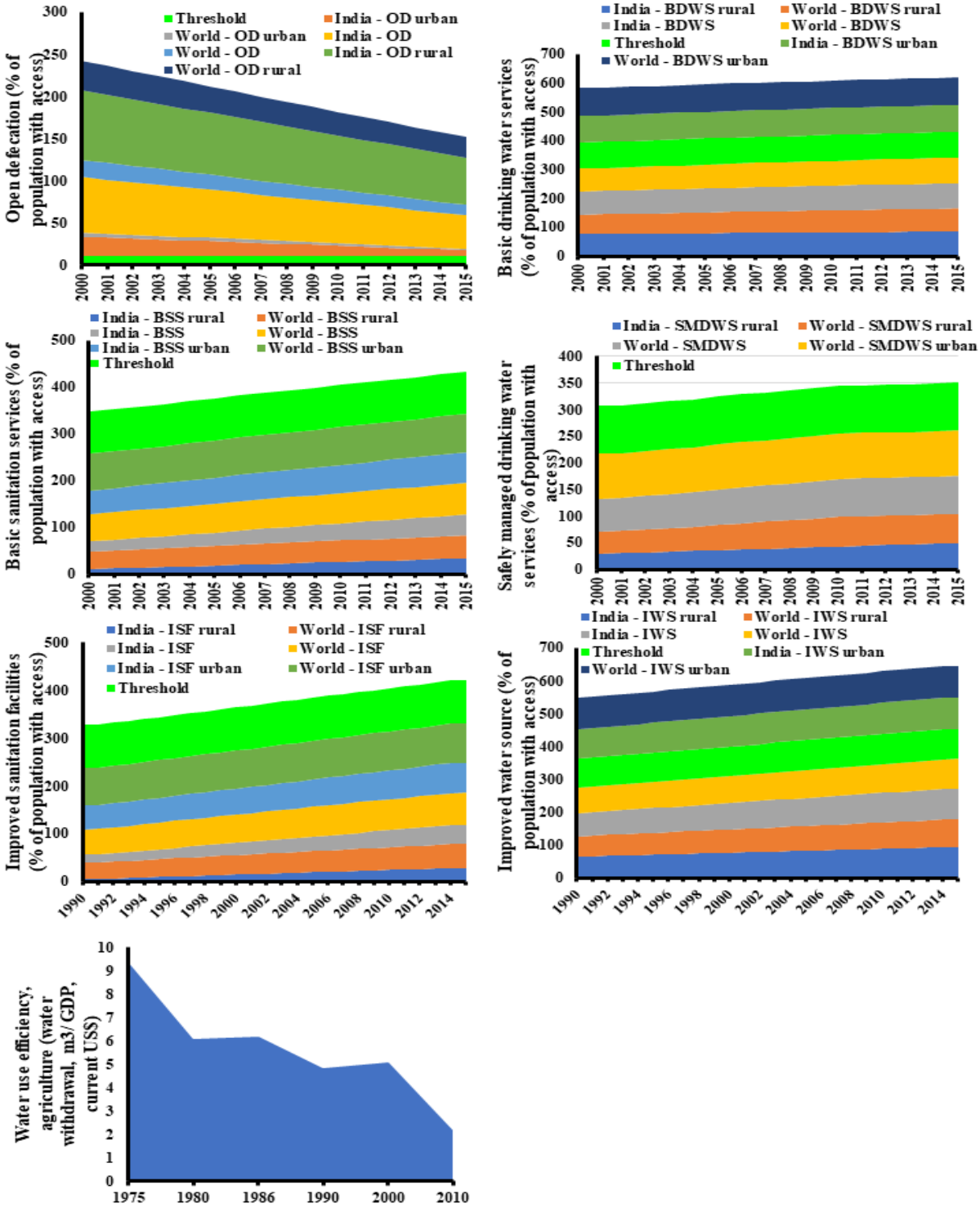

Open defecation (% of population with access)
Threshold
India - OD urban
World - OD urban
India - OD
World - OD
India - OD rural
World - OD rural
Basic drinking water services (% of population with access)
India - BDWS rural
World - BDWS rural
India - BDWS
World - BDWS
Threshold
India - BDWS urban
World - BDWS urban
Basic sanitation services (% of population with access)
India - BSS rural
World - BSS rural
India - BSS
World - BSS
India - BSS urban
World - BSS urban
Threshold
Safely managed drinking water services (% of population with access)
India - SMDWS rural
World - SMDWS rural
World - SMDWS
World - SMDWS urban
Threshold
Improved sanitation facilities (% of population with access)
India - ISF rural
World - ISF rural
India - ISF
World - ISF
India - ISF urban
World - ISF urban
Threshold
Improved water source (% of population with access)
India - IWS rural
World - IWS rural
India - IWS
World - IWS
Threshold
India - IWS urban
World - IWS urban
Water use efficiency, agriculture (water withdrawal, m3/GDP, current US$)

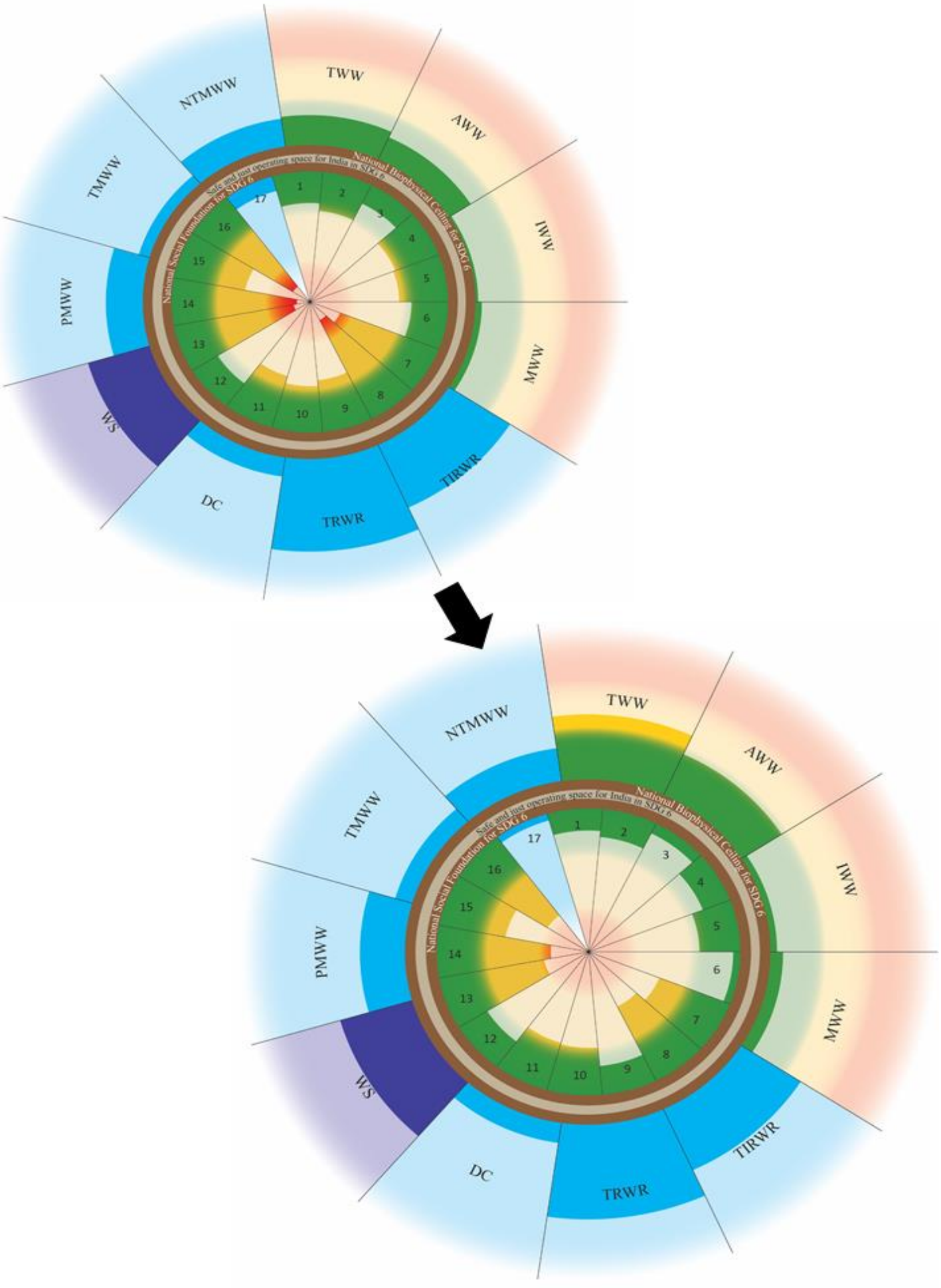
Fig 5. Trends of change in indicators of social development related to sustainable development goal 6 (water and sanitation) in India. Green indicates desirable thresholds for indicators of social development. (Objective 1, 3)

Table 11: Comparative change (2000 and 2015) among overall, rural and urban areas in social development indicators related to SDG 6 in India. (Objective 1, 3)

Indicators	Change (Overall area)	Change (Rural area)	Change (Urban area)
OD (India)	-26.14%	-26.59%	-16.08%
OD (World)	-8.32%	-10.59%	-2.69%
BDWS (India)	+7.15%	+9.16%	+0.44%

BDWS (World)	+8.45%	+12.58%	Almost same value (95.2%)
BSS (India)	+22.47%	+23.27%	+14.59%
BSS (World)	+9.99%	+11.66%	+3.68%
SMDWS (India)	NA	+20.19%	NA
SMDWS (World)	9.74%	13.86%	0.23%
ISF (India)	+22.8%	+22.9%	+13.3%
ISF (World)	+14.63%	+16.16%	+3.44%
IWS (India)	+23.6%	+28.4%	+8.2%
IWS (World)	+14.87%	+22.41%	+1.28%

Figure 6 depicts how much these 2 groups of indicators related to SDG 6 in India have changed with time (2000 and 2015).


TWW
AWW
IWW
MWW
TIRWR
TRWR
DC
WS
PMWW
TMWW
NTMWW
National Biophysical Ceiling for SDG 6
National Social Foundation for SDG 6
Safe and just operating space for India in SDG 6
1
2
3
4
5
6
7
8
9
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11
12
13
14
15
16
17

Fig 6. Changes in biophysical consumption and social development indicators related to sustainable development goal 6 (water and sanitation) in India.

Left and Right represent the status of sustainable development of water and sanitation in India in 2000 and 2015 respectively. 11 indicators of biophysical stress established over biophysical/ecological ceiling (outer chocolate ring) outwardly projected. Also 17 indicators of social development established under social foundation (inner chocolate ring) inwardly projected for India. (Objective 1, 3)

[Colour Scheme: Green = 'safe operating space' for biophysical indicators and 'just' thresholds for indicators of social development; Yellow = zone of increasing impact for biophysical indicators and zone of increasing deprivation for indicators of social development; Red = zone of high risk of serious impact for biophysical indicators and zone of high level of deprivation for indicators of social development; Light blue = indicators without any boundary or thresholds (Unit – m^3); Violet = water stress (Unit - %); Outer chocolate ring = National biophysical ceiling for SDG 6; Inner chocolate ring = National social foundation for SDG 6; Area between the chocolate rings = the 'safe and just operating space' for sustainable development of water and sanitation in India.]

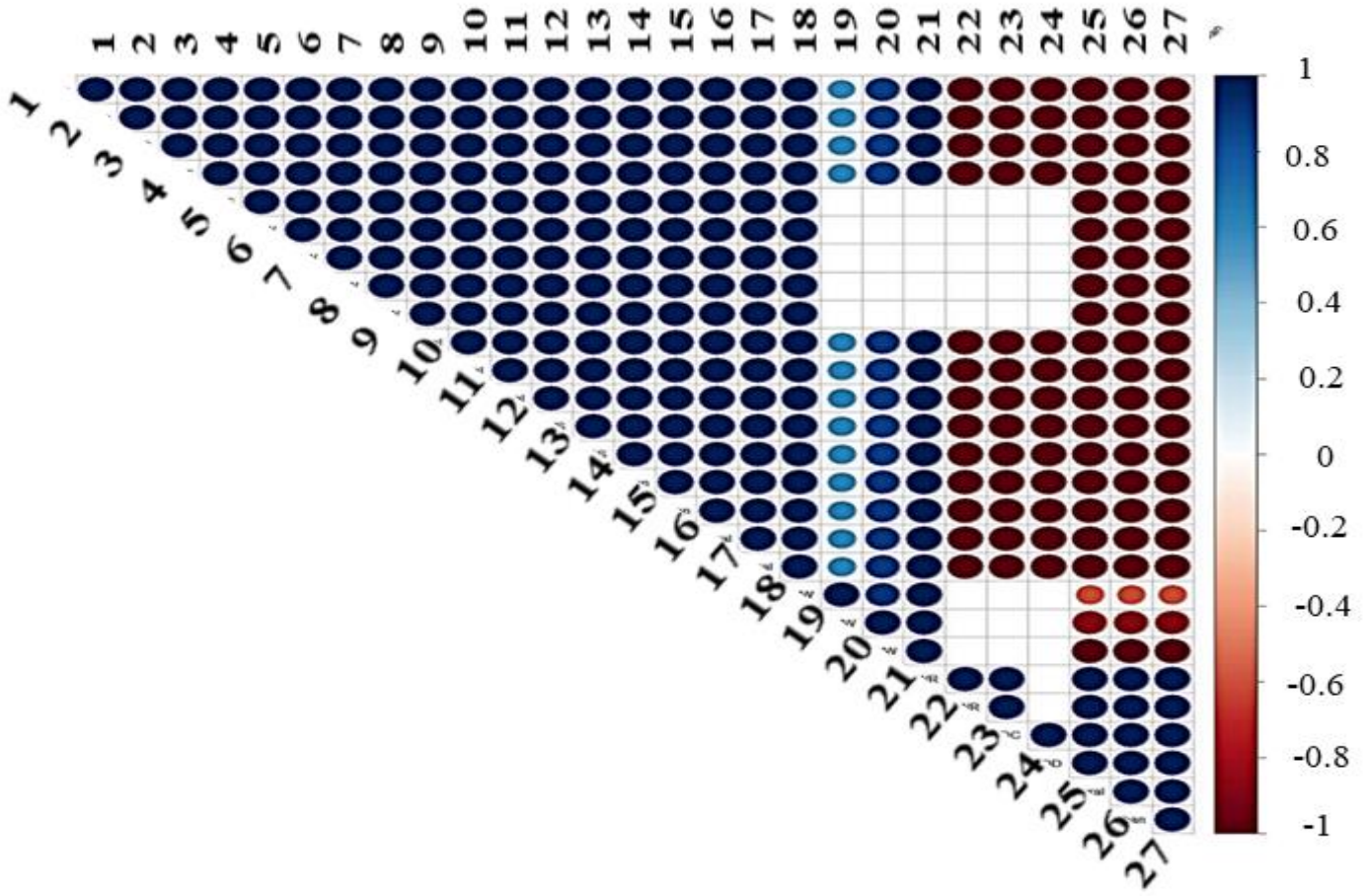


Fig 7. Correlogram of 27 indicators related to SDG 6 in India. It has been done using open source software 'R'. There are some gaps, due to unavailability of respective data.

The indicators are – (1) IWS, urban, (2) ISF, urban, (3) IWS, (4) ISF, (5) WS, (6) MWW, (7) IWW, (8) TWW, (9) AWW, (10) ISF, rural, (11) IWS, rural, (12) SMDWS, rural, (13) BDWS, (14) BSS, (15) BDWS, urban, (16) BSS, urban, (17) BDWS, rural, (18) BSS, rural, (19) NTMWW, (20) PMWW, (21) TMWW, (22) TIRWR, (23) TRWR, (24) DC, (25) OD, (26) OD, rural, (27) OD, urban.

(c) ***Future of water and sanitation (SDG 6):***

In 2050, if lowest per capita rate can be maintained, even with grown population level of 2050, it is possible to lower the rates of water resource consumption or restrict up to a certain level which is a significant amount for a water-dependent agroeconomic country like India (Table 12 and Figure 8).

Table 12: Changes in biophysical resource consumption related to SDG 6 in India based on 3 scenarios in future (2050). (Objective 2, 4)

No.	Indicators	Change (lowest rate, in 2050)	Change (BAU rate, in 2050)	Change (highest rate, in 2050)
1	TWW	+18.98%	+25.8%	+26.57%
2	AWW	+20.98%	+25.8%	+29.1%
3	IWW	-7.72%	+25.8%	+57.7%
4	MWW	-46.18%	+25.8%	
5	PMWW	-53.02%	+24.82%	
6	TMWW	-60.71%	+24.82%	
7	NTMWW	-56.83%	+24.82%	
8,9	TRWR, TIRWR	+22%		+72.15%

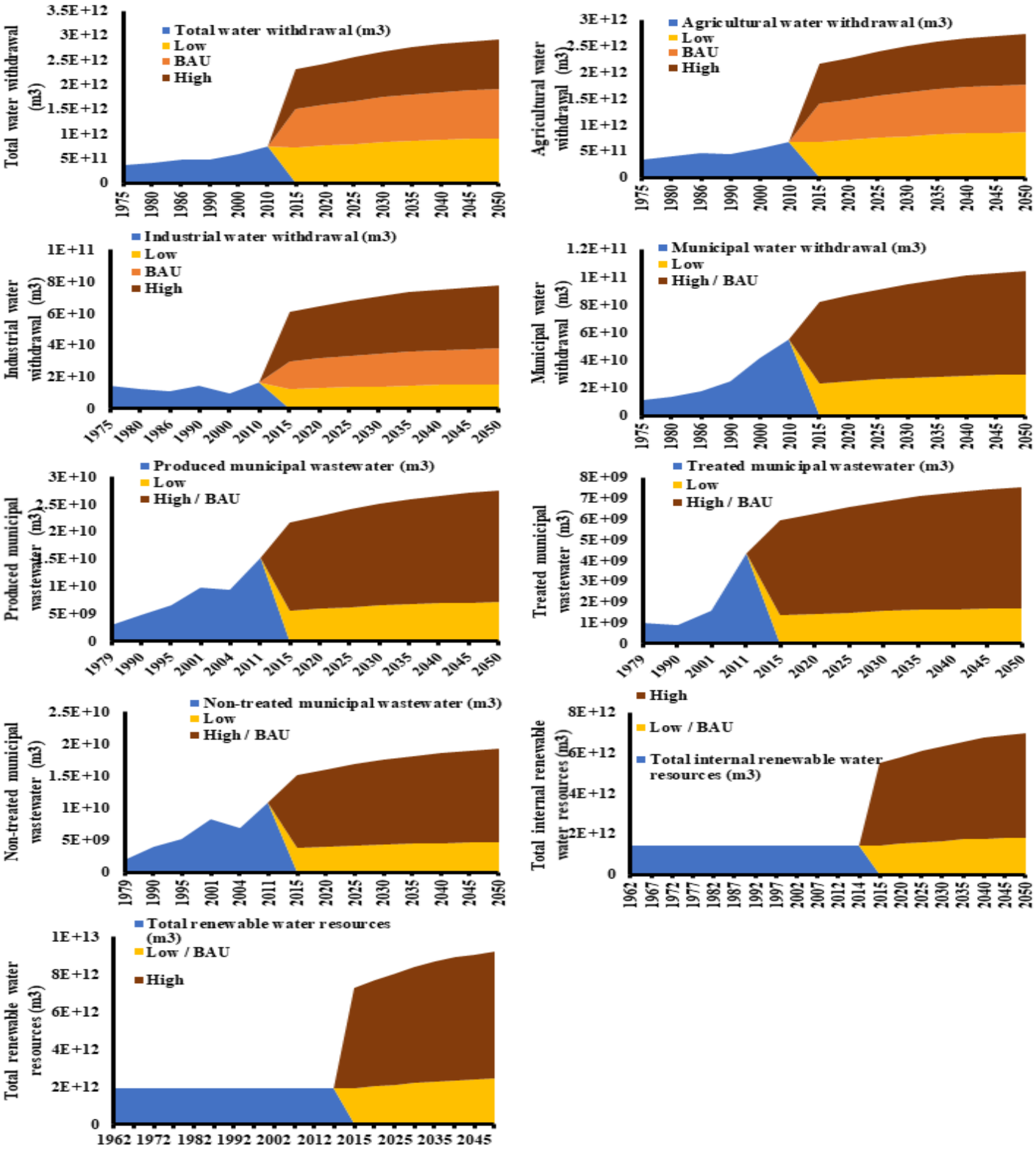


Fig 8. Future scenario of indicators of biophysical consumption related to sustainable development goal 6 (water and sanitation) for India up to 2050. (Objective 2, 4)

[Colour Scheme: Blue = changes in total values of biophysical consumption; Brown = projected total values at highest rate of per capita biophysical consumption; Orange = projected total values at BAU rate of per capita biophysical consumption; Yellow = projected total values at lowest rate of per capita biophysical consumption.]

(d) ***Relationship of SDG 6 with SDG 3 and SDG 1:***

OD and child mortality rate in India have decreased 26.7% and 78.1 in the same time. At global average level, they have also decreased 13.18% and 48.1, respectively. ISF and prevalence of stunting have changed (22.7% increase and 27.5% decrease). Also, at global average level, they have increased 14.61% and decreased 16.6%, respectively. With increasing access to ISF and IWS, number of annual deaths from diarrheal diseases have decreased (1990-2016), in both India and the World. Among the 5 age groups, 0-5y is the most affected age group (however, it has also decreased the most among other age groups), both for India and the World. Death rates from diarrheal diseases have also decreased, especially for 0-5y, 50-69y and 70 y+, for both India and the World. For risk factor of deaths from SDG6 related diseases, 0-5y is the most affected age group and has also improved the most over the years, in all the 3 types (NAHF, PS and UWS), for both India and the World (Figure 9-10).

GDP is clearly influencing water and sanitation related developments, both in India and the World, but to varying degrees (Table 13).

Table 13: Comparative change among overall, rural and urban areas in social development indicators related to SDG 6 with GDP per capita in India and World. (Objective 1, 3)

No.	**Indicators**	**Nature of change with GDP per capita (current US$)**		
		Overall area	**Rural area**	**Urban area**
1	BDWS (India)	Most		Very less
	BDWS (World)	Moderate		Very less
2	BSS (India)	Most		
	BSS (World)	Moderate		
3	ISF (India)	Most		Moderate
	ISF (World)	Moderate		Very less
4	IWS (India)	Most		Moderate
	IWS (World)	Moderate		Very less
5	OD (India)	Most		
	OD (World)	Moderate		Very less
6	SMDWS (India)	NA	Most	NA
	SMDWS (World)	Moderate		Very less

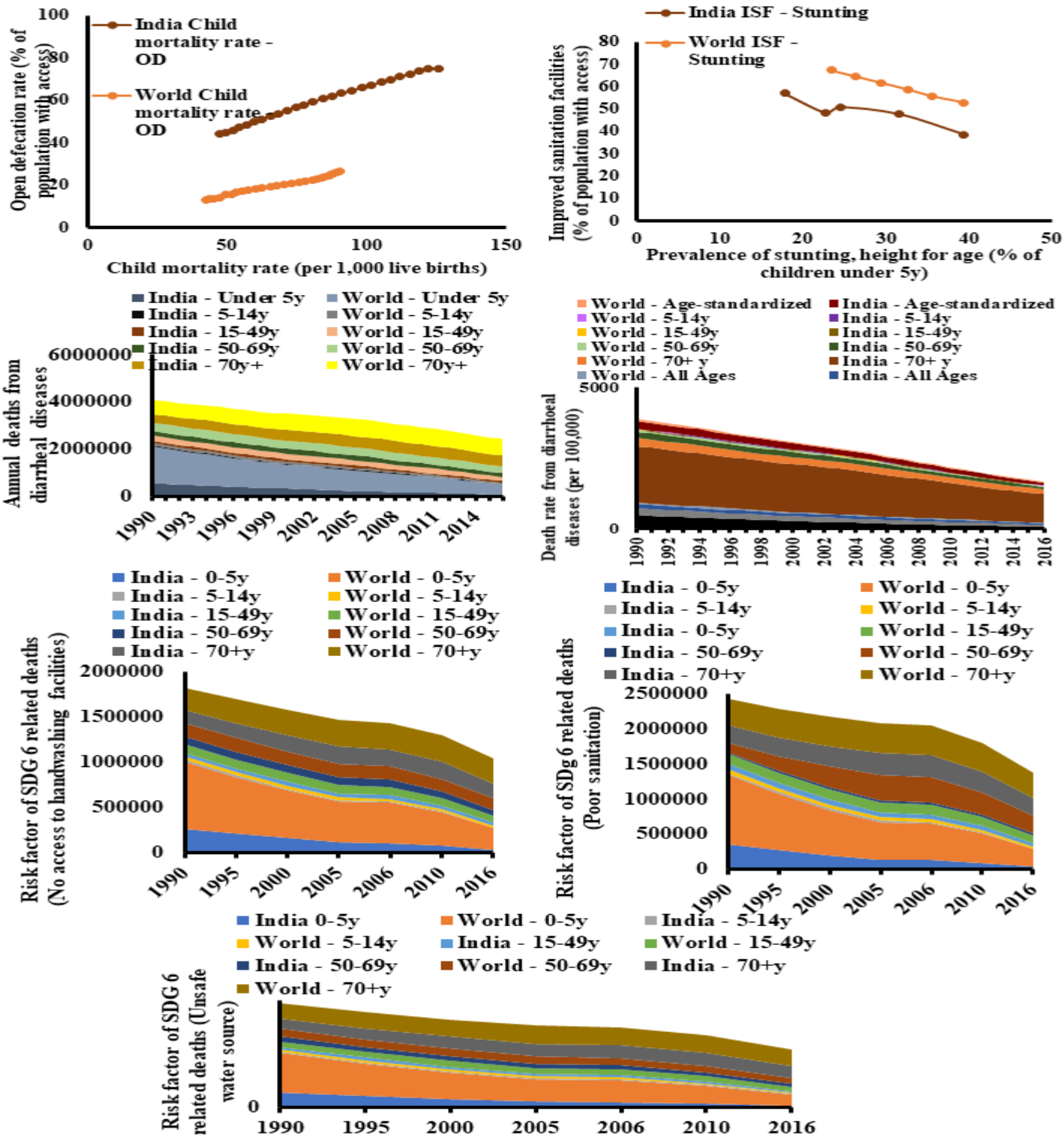

India Child mortality rate - OD
World Child mortality rate - OD
Open defecation rate (% of population with access)
Child mortality rate (per 1,000 live births)
India ISF - Stunting
World ISF - Stunting
Improved sanitation facilities (% of population with access)
Prevalence of stunting, height for age (% of children under 5y)
India - Under 5y
India - 5-14y
India - 15-49y
India - 50-69y
India - 70y+
World - Under 5y
World - 5-14y
World - 15-49y
World - 50-69y
World - 70y+
Annual deaths from diarrheal diseases
World - Age-standardized
World - 5-14y
World - 15-49y
World - 50-69y
World - 70+ y
World - All Ages
India - Age-standardized
India - 5-14y
India - 15-49y
India - 50-69y
India - 70+ y
India - All Ages
Death rate from diarrhoeal diseases (per 100,000)
India - 0-5y
India - 5-14y
India - 15-49y
India - 50-69y
India - 70+y
World - 0-5y
World - 5-14y
World - 15-49y
World - 50-69y
World - 70+y
Risk factor of SDG 6 related deaths (No access to handwashing facilities)
Risk factor of SDg 6 related deaths (Poor sanitation)
India 0-5y
World - 0-5y
India - 5-14y
World - 5-14y
India - 15-49y
World - 15-49y
India - 50-69y
World - 50-69y
India - 70+y
World - 70+y
Risk factor of SDG 6 related deaths (Unsafe water source)

Fig 9. Interrelationship of water and sanitation (SDG 6) with Health (SDG 3) for India and world. (Objective 1, 3)

SDG 6 - SDG 3 interrelationships are represented by – (1) child mortality rate vs. OD, (2) prevalence of stunting vs. ISF, (3) annual deaths from diarrheal diseases, (4) death rate from diarrheal diseases and (5) risk factor of water and sanitation related deaths. (Objective 1, 3)

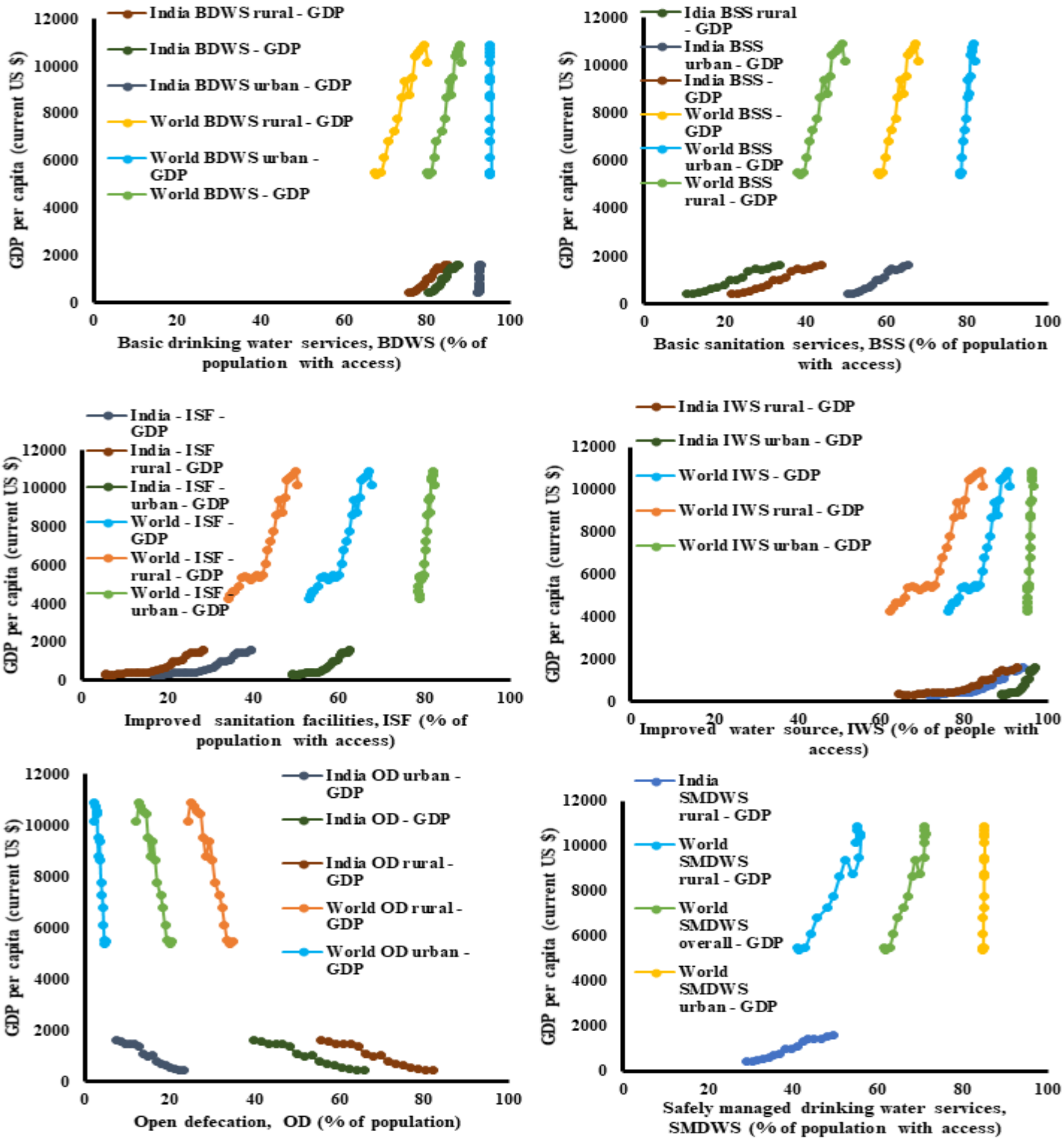

India BDWS rural - GDP
India BDWS - GDP
India BDWS urban - GDP
World BDWS rural - GDP
World BDWS urban - GDP
World BDWS - GDP
GDP per capita (current US $)
Basic drinking water services, BDWS (% of population with access)
Idia BSS rural - GDP
India BSS urban - GDP
India BSS - GDP
World BSS - GDP
World BSS urban - GDP
World BSS rural - GDP
GDP per capita (current US $)
Basic sanitation services, BSS (% of population with access)
India - ISF - GDP
India - ISF rural - GDP
India - ISF - urban - GDP
World - ISF - GDP
World - ISF - rural - GDP
World - ISF urban - GDP
GDP per capita (current US $)
Improved sanitation facilities, ISF (% of population with access)
India IWS rural - GDP
India IWS urban - GDP
World IWS - GDP
World IWS rural - GDP
World IWS urban - GDP
GDP per capita (current US $)
Improved water source, IWS (% of people with access)
India OD urban - GDP
India OD - GDP
India OD rural - GDP
World OD rural - GDP
World OD urban - GDP
GDP per capita (current US $)
Open defecation, OD (% of population)
India SMDWS rural - GDP
World SMDWS rural - GDP
World SMDWS overall - GDP
World SMDWS urban - GDP
GDP per capita (current US $)
Safely managed drinking water services, SMDWS (% of population with access)

Fig 10. Interrelationship of water and sanitation (SDG 6) with End to poverty (SDG 1) for India.

SDG 6 - SDG 1 interrelationships are represented by – (1) BDWS vs. GDP, (2) BSS vs. GDP, (3) ISF vs. GDP, (4) IWS vs. GDP, (5) OD vs. GDP and (6) SMDWS vs. GDP. (Objective 1, 3)

[Colour Scheme: Darker version of colors = India; Lighter version of that colour = Global average values]

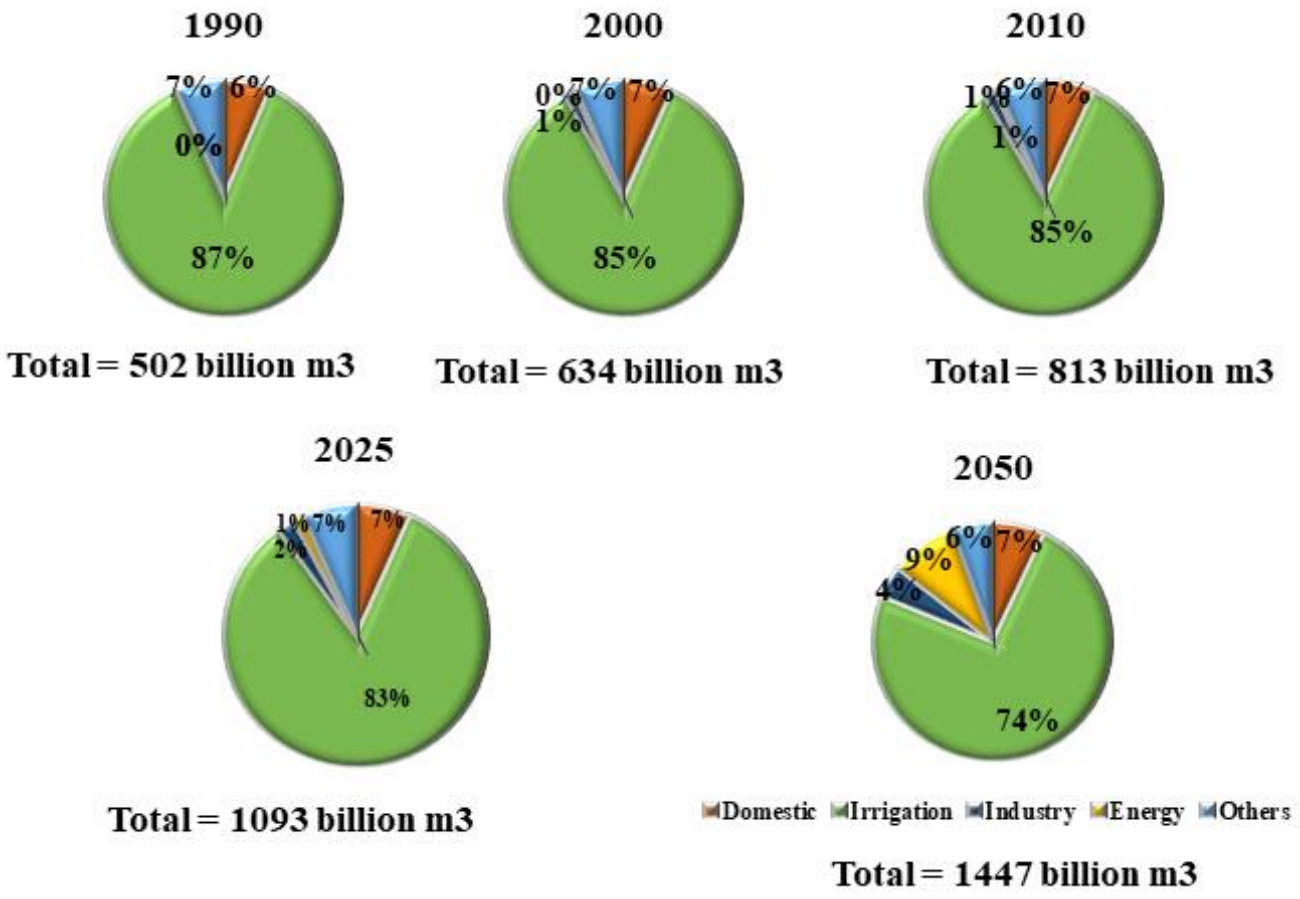


Fig 11: Trends of annual requirement of water in different sectors in India.

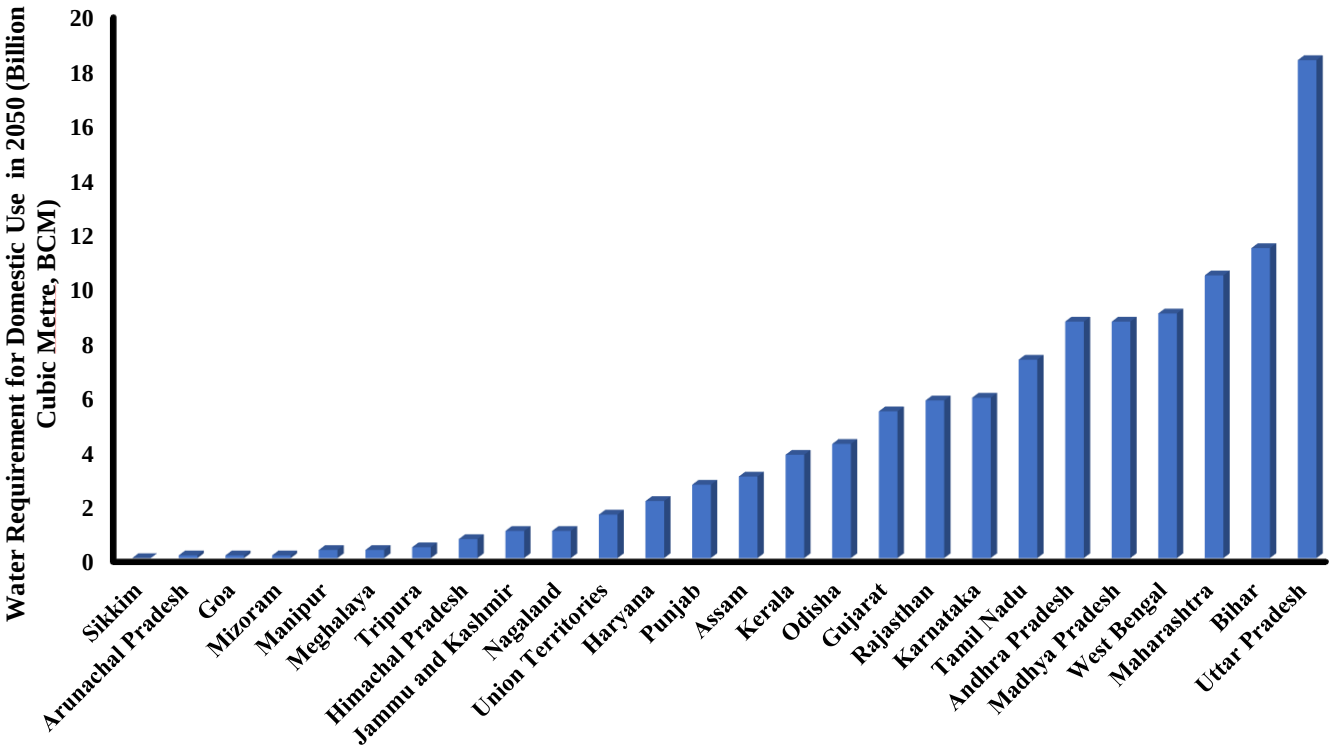


Fig 12. Probable water requirement for domestic purposes in Indian states in 2050.

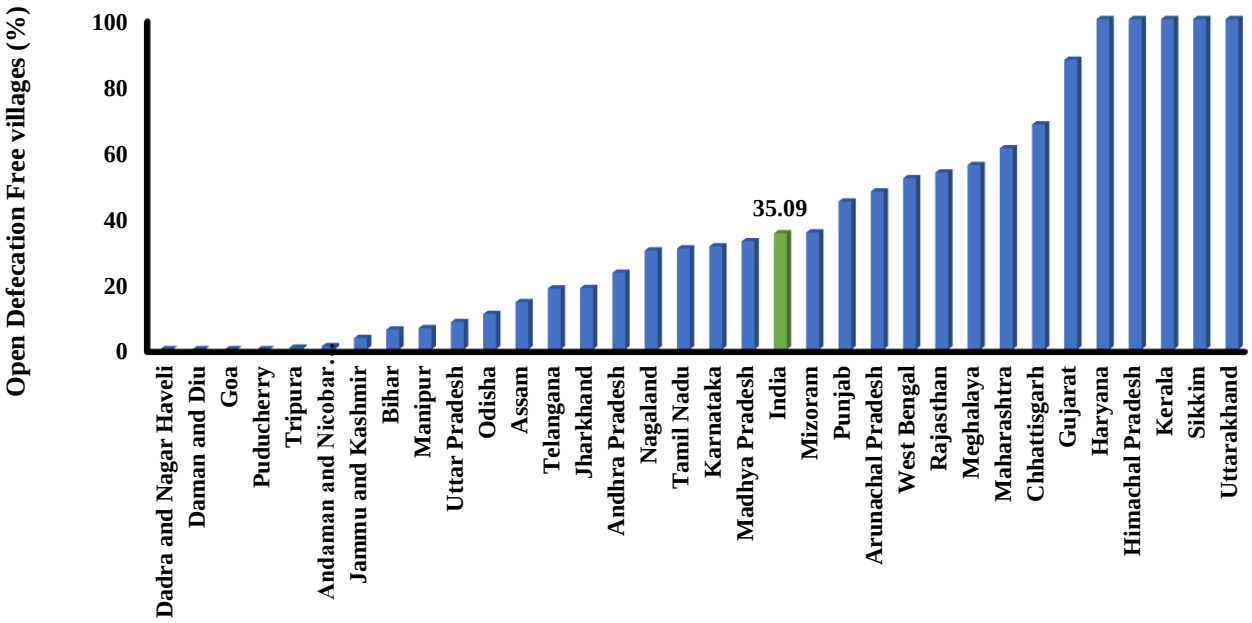


Fig 13. Open defecation free (ODF) villages in states and union territories (UTs) in India.

Chapter 3

'Safe and Just Operating Space' of Agriculture in India

Methodology:

(a) *Planetary boundaries of agriculture*:

We have analysed various biophysical consumption factors related to the agriculture, as – climate change, freshwater use, arable land use, nitrogen use, phosphorus use, ecological footprint, atmospheric pollution and novel entities. These are shown in table 14.

Table 14: Biophysical indicators of planetary boundaries related to agriculture. These indicators are - climate change, freshwater use, arable land use, nitrogen use, phosphorus use, ecological footprint, atmospheric pollution and novel entities. (Objective 1, 3)

Dimensions (related SDGs)	**Indicators with units**	**Duration**	**Data Sources**
Climate change (SDG 13)	Agricultural GHG emissions (t CO_2-e) Per Capita Per Year	1990-2014	CAIT
Freshwater use (SDG 6)	Agricultural water withdrawal (m^3) Per Capita Per Year	1973-2012	Aquastat
	Agricultural WF of consumption (% of total)	1996-2005	WaterStat
	Agricultural blue WF of consumption (% of total blue WF)		
	Agricultural grey WF of consumption (% of total grey WF)		
Arable land use (SDG 15)	Agricultural land area (ha) Per Capita Per Year	1961-2015	FAOSTAT; WDI
Nitrogen use (SDG 14)	Nutrient nitrogen N use (kg) Per Capita Per Year	2002-2015	FAOSTAT
Phosphorus use (SDG 14)	Nutrient phosphate P_2O_5 use (kg) Per Capita Per Year	2002-2015	
Ecological footprint (SDG 14, SDG 15)	Ecological footprint (cropland EF) Per Capita (gha) Per Year	1961-2016	GFN
Air pollution (SDG 13)	Per capita (kg) of BC, CO, NH_3, NMVOC, NOx, OC, PM_{10},	1970-2012	EDGAR v4.3.2

	$PM_{2.5}$ bio, $PM_{2.5}$ fossil, SO_2,		
Novel Entities (SDG 14, SDG 15)	Pesticides use per area of cropland (kg per ha)	1990-2016	FAOSTAT; WDI,
	Pesticides (total) use of active ingredients Per Capita (kg) Per Year		
	Synthetic fertilizer uses Per Capita (kg) Per Year	1961-2001	

(b) *Doughnut economy of Agriculture*:

We have also analysed various socioeconomic factors related to the agriculture, as – income (via GDP and GNI), employment, value added by agriculture and share of agriculture in male and female employment, which are in turn connected to UN SDG 1, 5 and 8; and 3 dimensions of doughnut economy (income, job, gender equality) (20, 21) (Table 15).

Table 15: Socioeconomic development indicators of doughnut economy related to agriculture. The factors are – poverty, gender equality, employment and economic growth. (Objective 1, 3)

Dimensions (related SDGs)	Indicators (Unit)	Duration	Data Source
Poverty (SDG 1)	GDP per capita (current US$)	1960-2015	WDI
	GNI per capita (constant 2010 US$)	1970-2016	
Gender Equality (SDG 5)	Female employment in agriculture	1991-2018	
	Male employment in agriculture		
Employment (SDG 8)	Employment in agriculture		
Economic growth (SDG 8)	Agriculture, forestry, and fishing, value added (% of GDP)	1960-2017	

(c) *Future scenario of Agriculture*: To project probable future scenario of total biophysical consumption, future (2015-2050) population projection (median range prediction value of 50%) of India is to be integrated with per capita consumption of each dimension of PBs. 3 projection series for each dimension of PBs has also been calculated that are based on - (1) lowest consumption value, (2) highest consumption value and (3) BAU scenario.

Results:

(a) Planetary boundaries:

Climate change: Agricultural GHG emission has decreased in the world (16.59%), Asia (5.87%) and India (24.41%) from 1990 level. This agricultural GHG emission is higher than global average per capita climate change PB in the world (12.76%), but lowers in India (24.29%) and Asia (16.34%).

Freshwater use: In total WF of consumption, agriculture's contribution is now 91.5%, i.e., it has increased by 5.66%, globally. As per the latest available data, agriculture is responsible for 91.56% of blue WF and 51.6% of grey WF of consumption at a global level. For India, blue WF is 18.92% lower than per capita average blue water PB for agriculture.

Arable land use:

Arable land area (ha per capita) have decreased significantly for the world (53.79%), Asia (54.16%), since the 1961 level. Arable land area (per capita) is higher than land use PB in the world (13.61%), but lower in India (19.24%), Asia (34.04%), southern Asia (28.82%) and south-eastern Asia (34.91%). Agriculture's share of land use used to be high in almost all over the world except for a few countries in 1961. This situation has remained the same at the present time but deteriorated in countries of Asia and Africa in 2015.

Nitrogen use:

Nitrogen use (kg) per capita has increased in the world (12.99%), Asia (17.95%) than 2002 level. Agricultural nitrogen use is lower than per capita nitrogen use PB for agriculture in the world (84.15%), Asia (84.13%), southern Asia (86.27%) and south-eastern Asia (87.63%); but higher in India (42.09%). Nitrogen use in agriculture (%) is presently more than 95% in all of the continents along with the world, except – North America (78.41%). Also, it has been increasing in all, except – Africa and Oceania (0.05% and 0.09% decrease).

Phosphorus use:

Phosphorus use (kg per capita) has increased in the world (18.48%) and Asia (31.39%) from 2002 levels. Almost all of these groups have crossed the phosphorus use PB, like – world (199.34%), Asia (204.84%) and India (133.36%). Phosphorus use in agriculture (%) is decreasing in the world (6.98%) than 2002 level.

Ecological footprint:

Cropland EF per capita (gha) has been increased significantly in India (1.81%), Asia (55.22%) and the word (14.86%), since 1961 level. Present level of cropland EF contributes a sizable portion to global average per capita ecological footprint PB, like – India (21.16%), Asia (30.17%) and the word (33.2%). The contribution of agriculture (i.e. cropland EF) to the total ecological footprint of consumption has decreased in India (25.22%), Asia (11%), southern Asia (23.86%) and the world (0.87%).

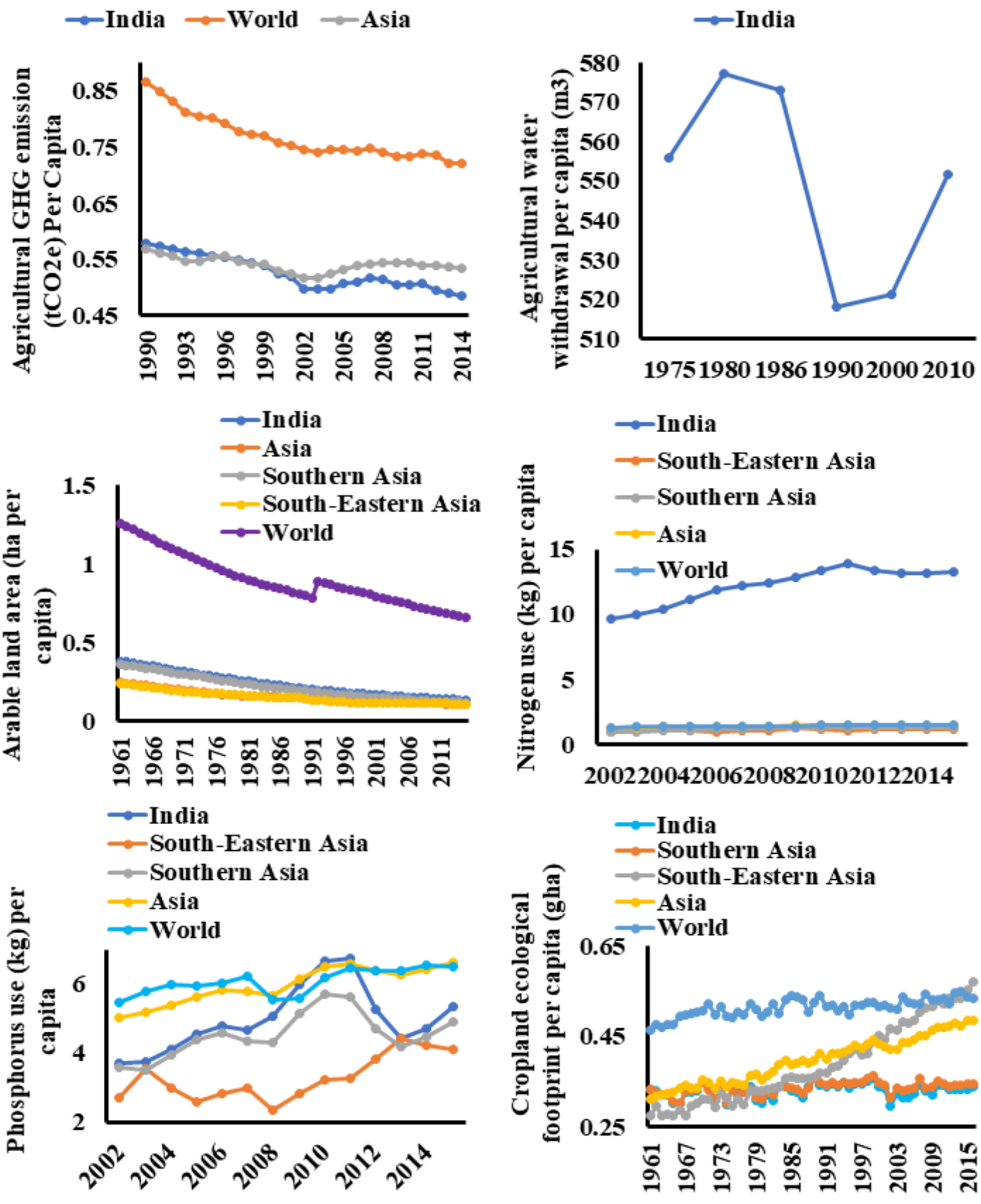


Fig 14a: Trends of biophysical resource consumption (per capita) of agriculture in India. (Objective 1, 3)

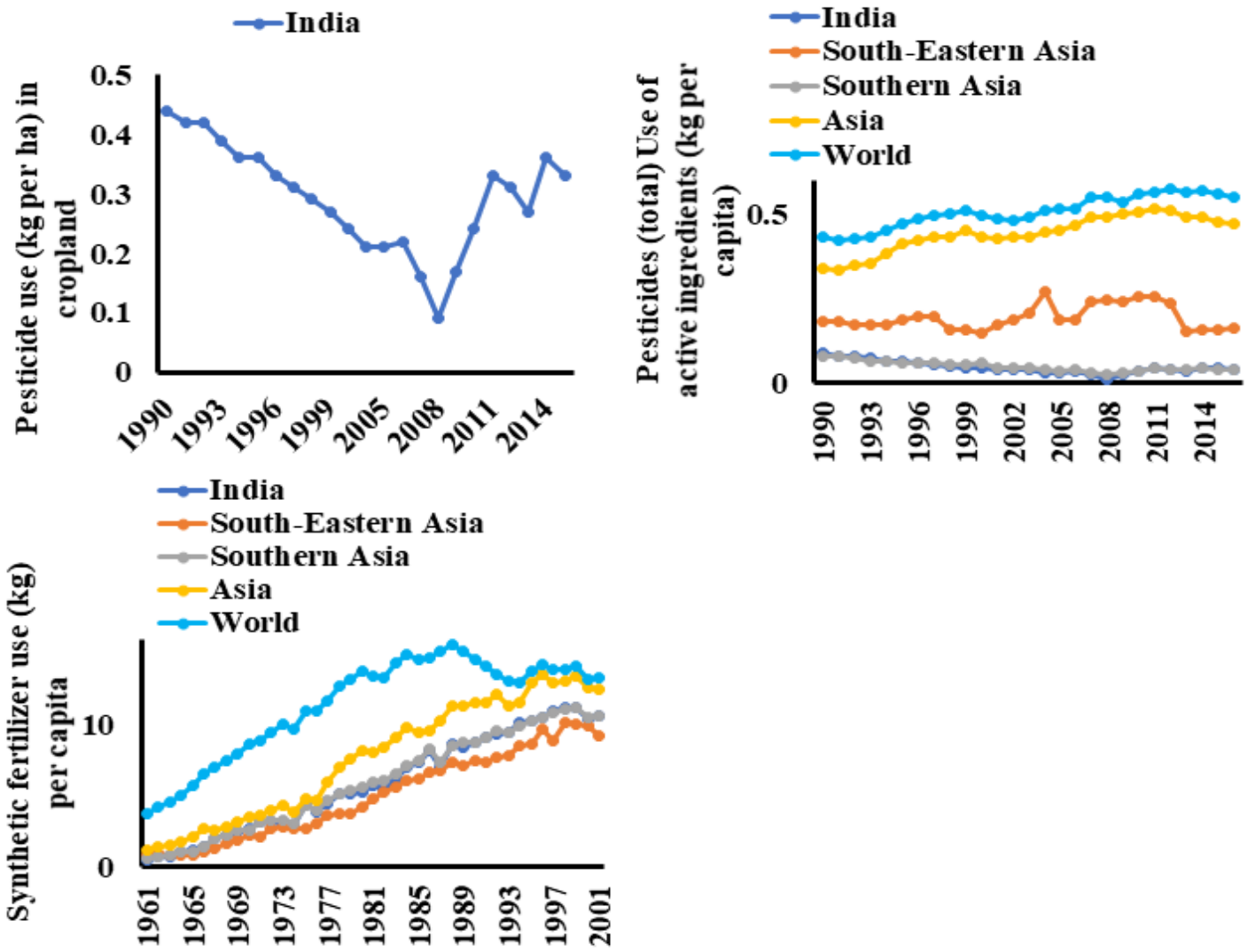


Fig 14b: Trends of biophysical resource consumption (per capita) of agriculture in India. (Objective 1, 3)

Air pollution:

Ammonia emission from agricultural sources was high in northern Asia in the 1970s. Now it's high in the southeast and north Asia. Black carbon emission from agricultural sources was high south & southeast Asia during the 1970s. Carbon monoxide emission from agricultural sources was high (the 1970s) in south, southeast & West Asia. Agricultural emission of oxides of nitrogen was high in south & Southeast Asia. But presently it's almost same except – decrease in south & Southeast Asia. Non-methane volatile organic compounds emission from agricultural sources was very low except for a few countries in Southeast Asia during the 1970s. But now it has increased in South Asia. Organic carbon emission from agricultural sources was high in Middle East and Southeast Asia during the 1970s. Presently, it's very high in parts of south & Southeast Asia; moderately high in north & West Asia. $PM_{2.5}$ (bio) emission from agricultural sources was very high in most of Asia during the 1970s. Now it's even higher in

most of Asia. PM $_{2.5}$ (fossil) emission from agricultural sources was comparatively higher in South & Southeast Asia. Presently it's decreased in all of those parts of the world. PM $_{10}$ from agricultural sources was moderately high in almost all of Asia. Now it has further increased. SO_2 emission from agricultural sources was very low all over the world, except – south & Southeast Asia during 1970s. But, now it's slightly high in Southeast Asia. At the global average level, the contribution of agriculture has decreased in all the of these air pollutants (except - increase in CO, NH_3 and OC).

Novel entities:

Synthetic fertilizer use (kg/capita) has increased at a very high rate in the world (251.46%) and Asia (920.03%) since 1961 level. Use of active ingredients of pesticides (kg/capita) has increased in the world (27.65%) and Asia (38.8%), since 1990 level. Agricultural pesticide uses per area of cropland (kg/ha) have increase relatively more in the world (41.63%) and Asia (41.44%) from 1990 level. In Asia, eastern and western part has increased (51.69 & 43.12%), but southern, south-eastern and central part has decreased (30, 2.25 & 21.82%, respectively).

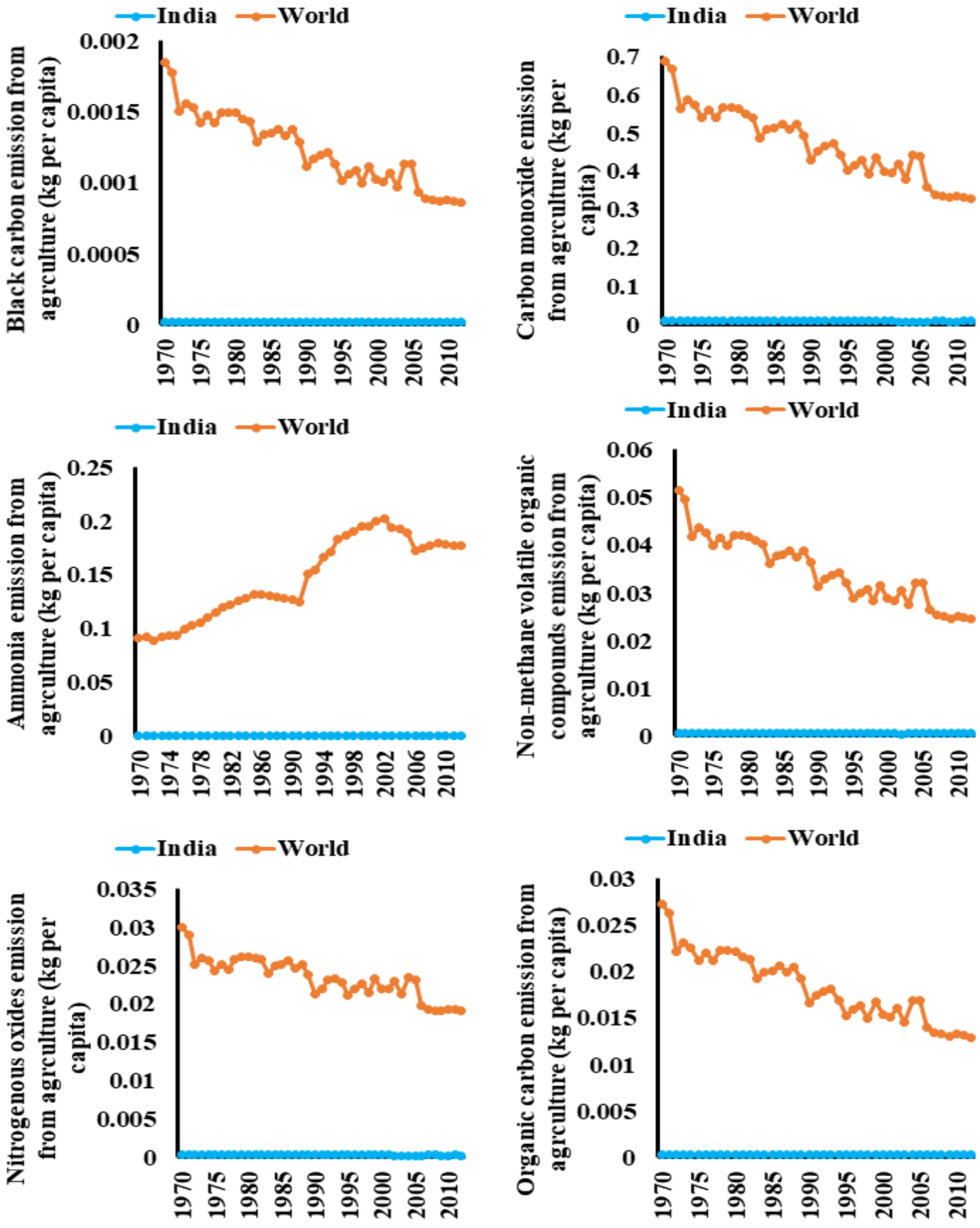


Fig 15a: Trends of emission of atmospheric pollution (per capita) from agriculture in India. (Objective 1, 3)

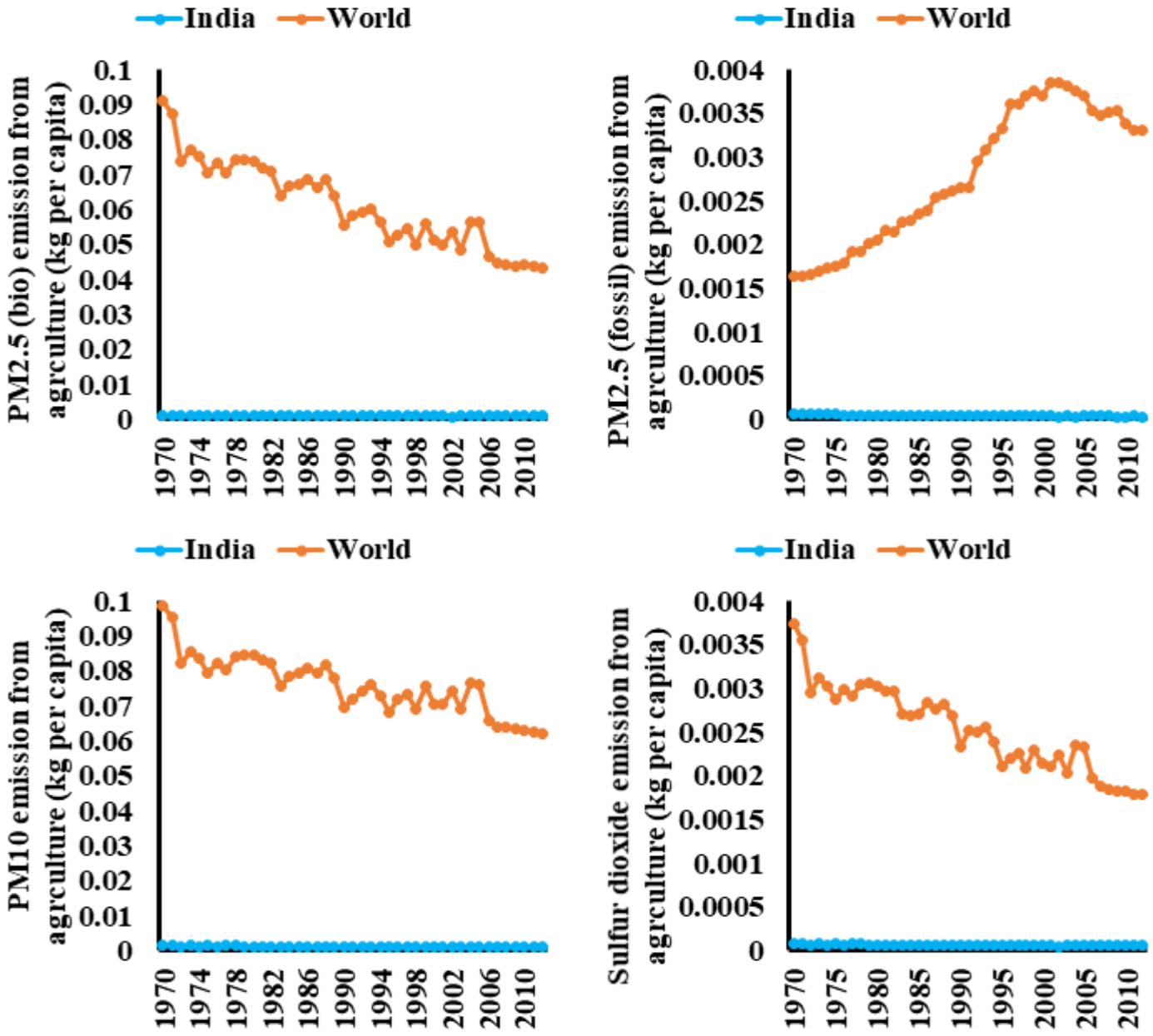


Fig 15b: Trends of emission of atmospheric pollution (per capita) from agriculture in India. (Objective 1, 3)

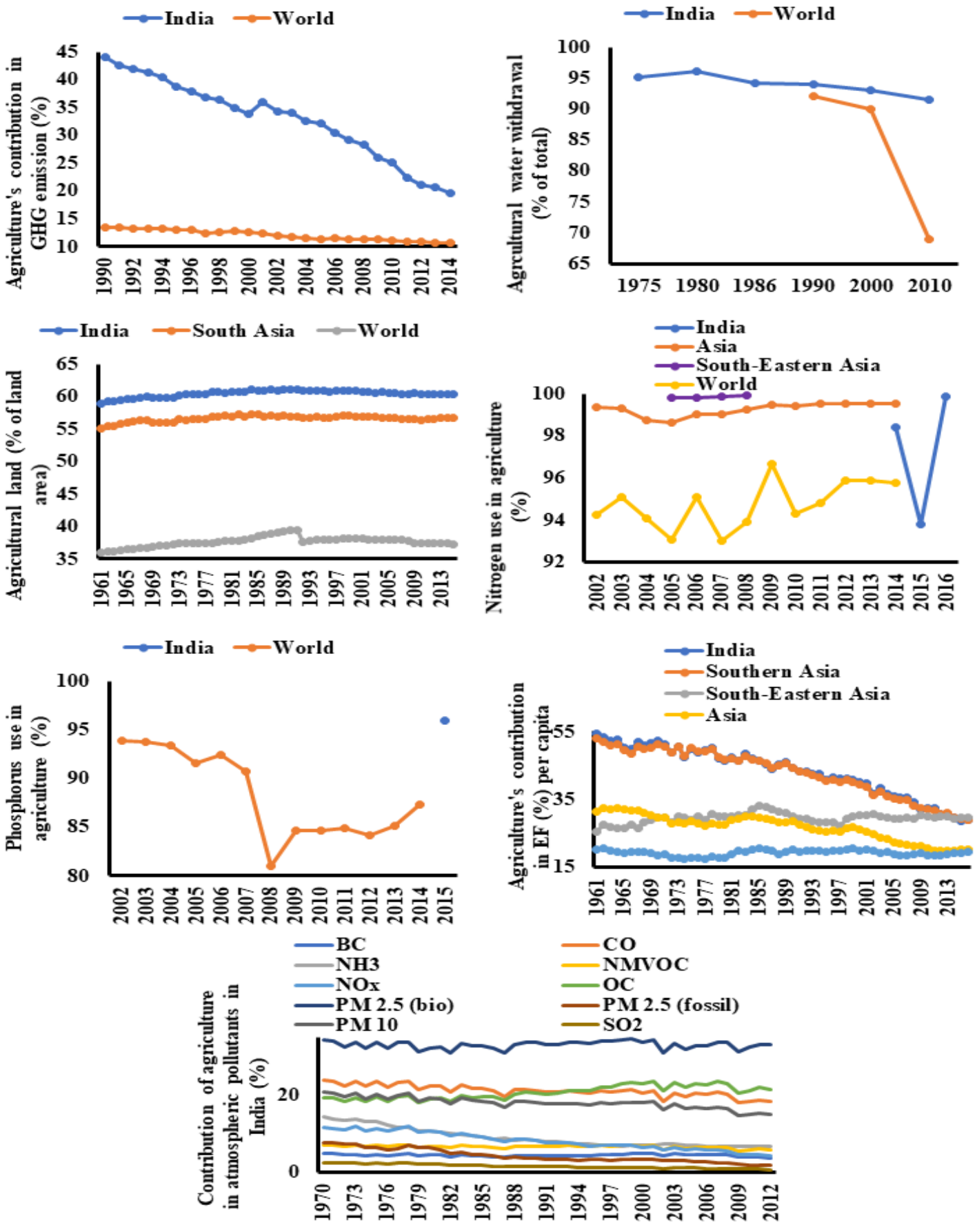


Fig 16: Trends of contribution of agriculture (%) in biophysical resource consumption in India. (Objective 1, 3)

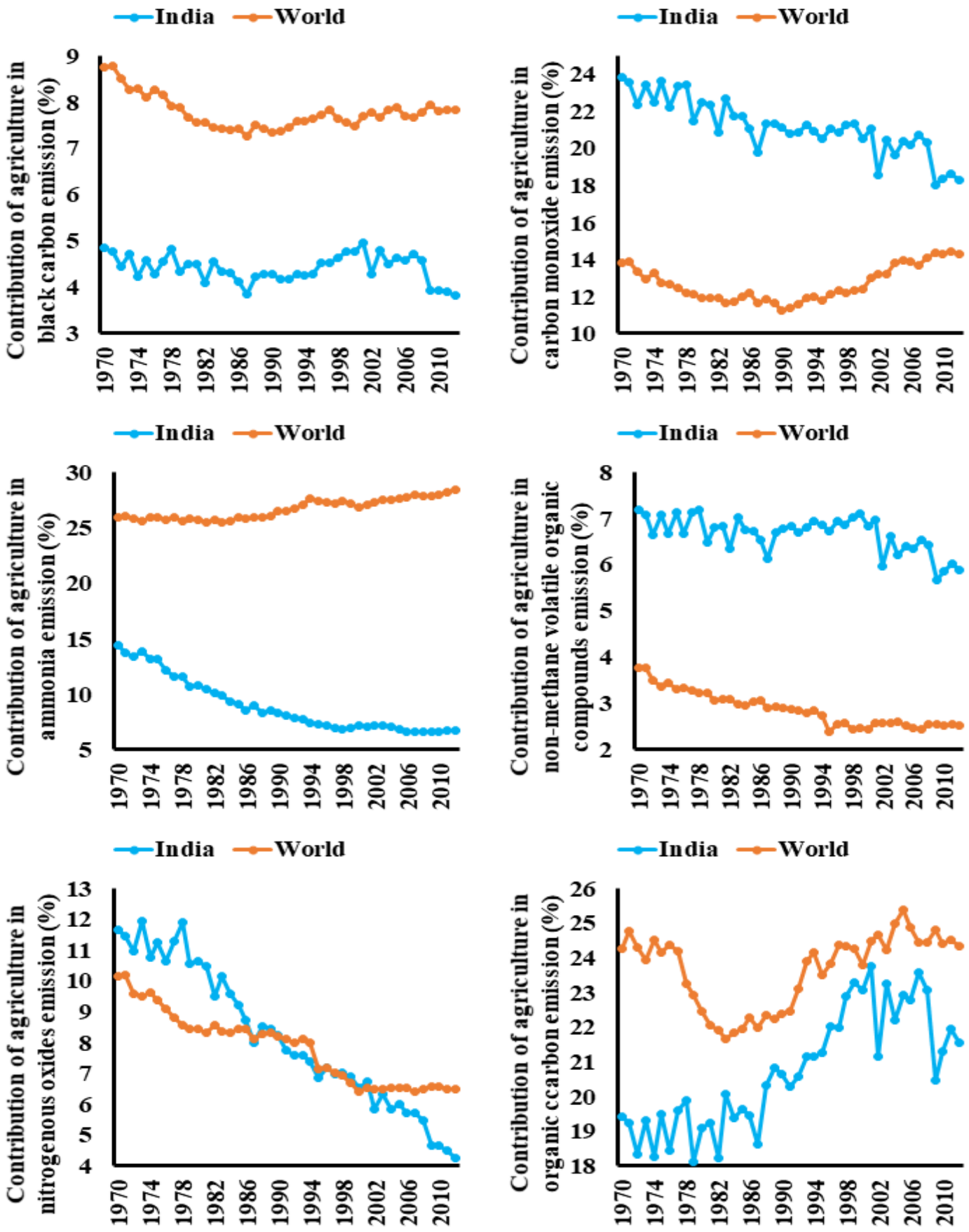


Fig 17a: Trends of contribution of agriculture (%) in atmospheric pollution in India. (Objective 1, 3)

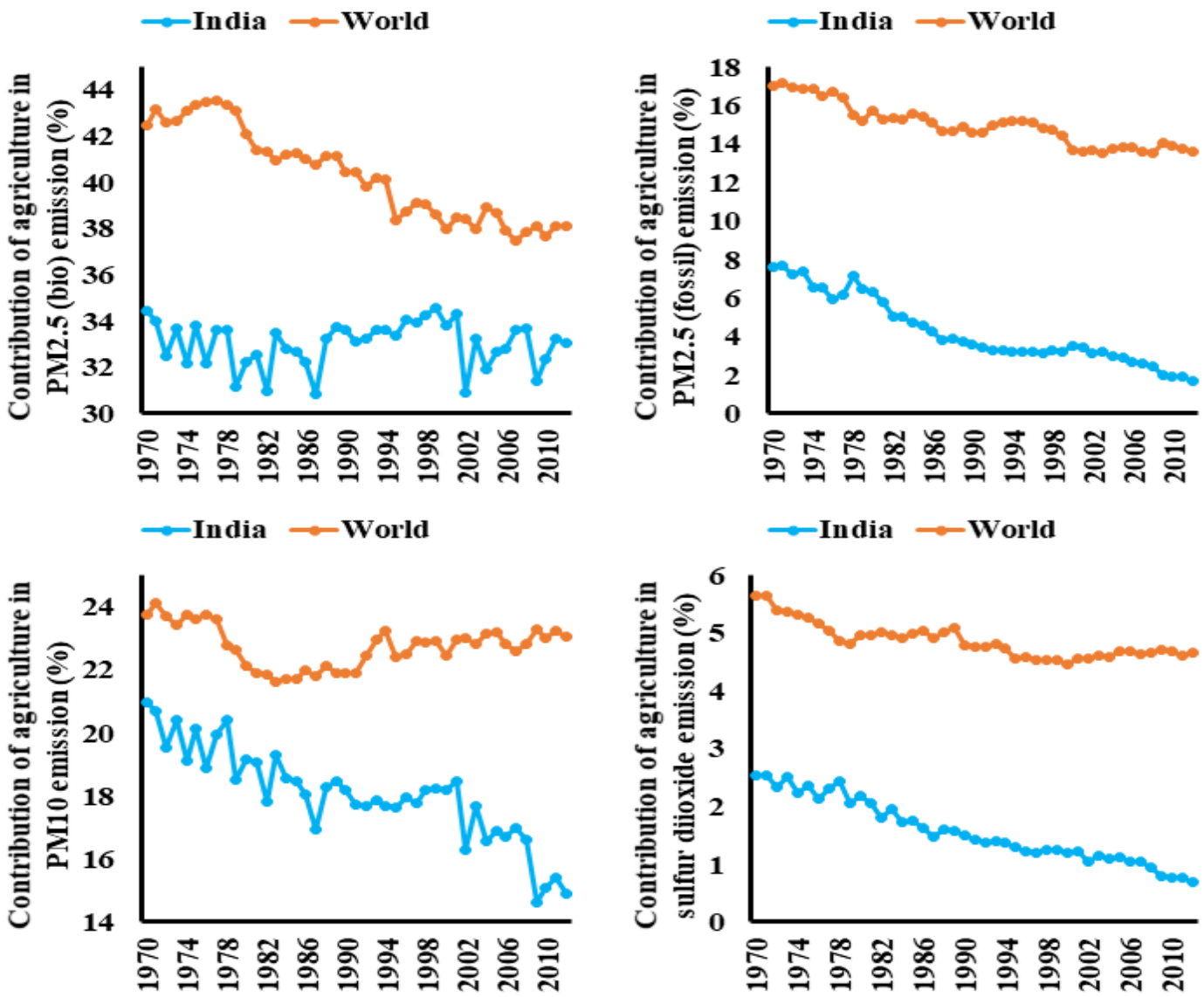
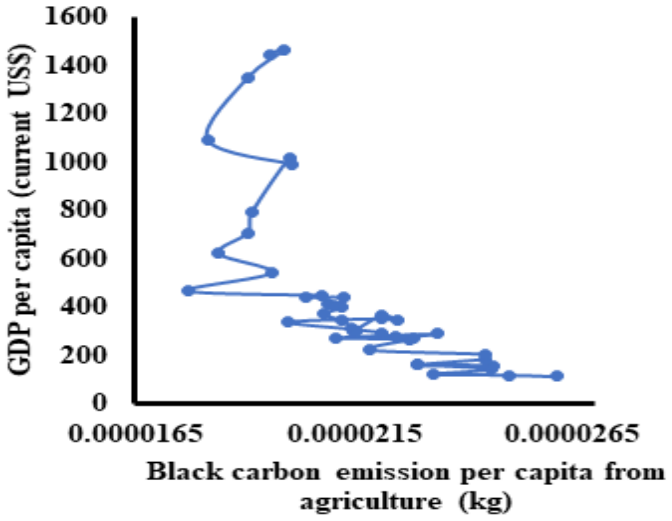
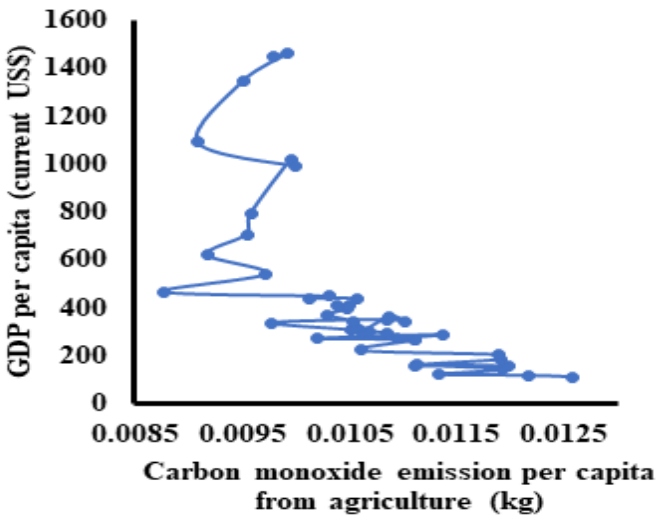
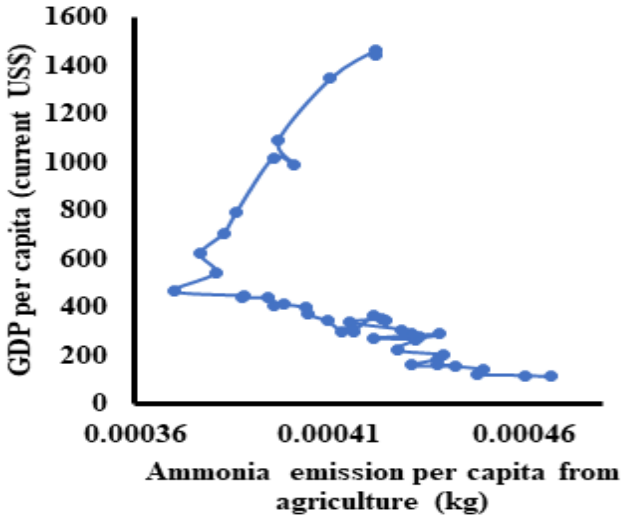
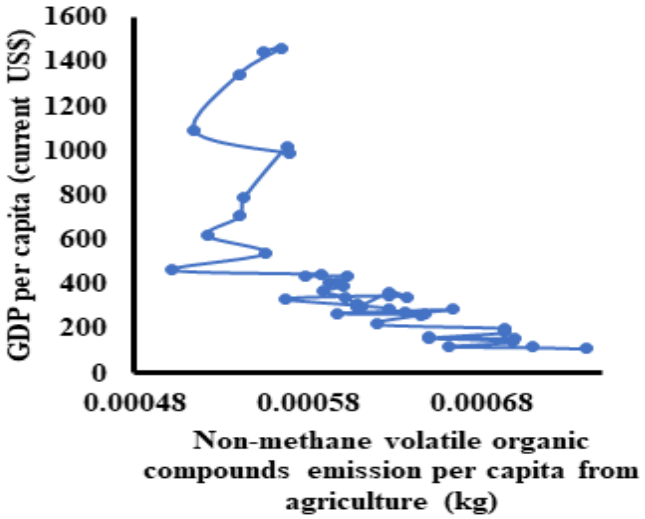

India
World
Contribution of agriculture in PM2.5 (bio) emission (%)
Contribution of agriculture in PM2.5 (fossil) emission (%)
Contribution of agriculture in PM10 emission (%)
Contribution of agriculture in sulfur dioxide emission (%)

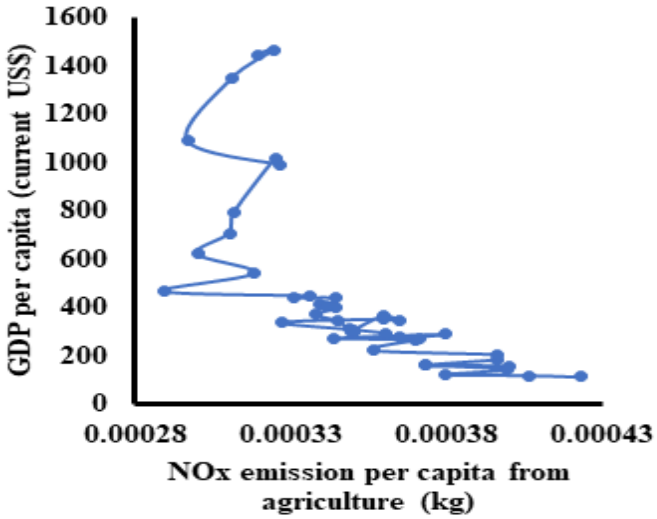
Fig 17b: Trends of contribution of agriculture (%) in atmospheric pollution in India. (Objective 1, 3)











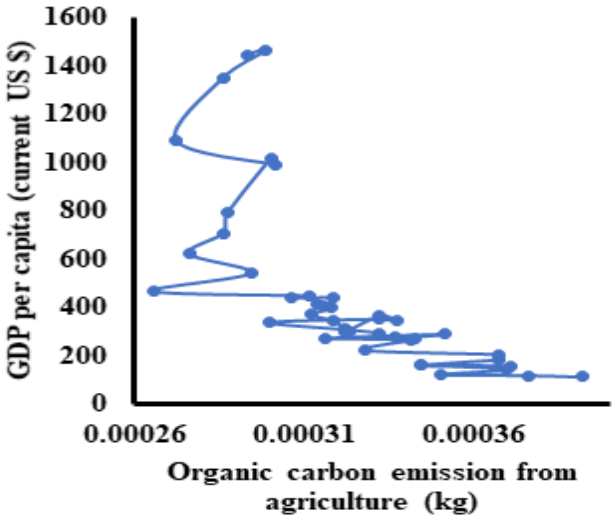


Fig 18a: Changes in emission of indicators of atmospheric pollution (per capita) from agriculture with respect to GDP per capita (current US$) in India.

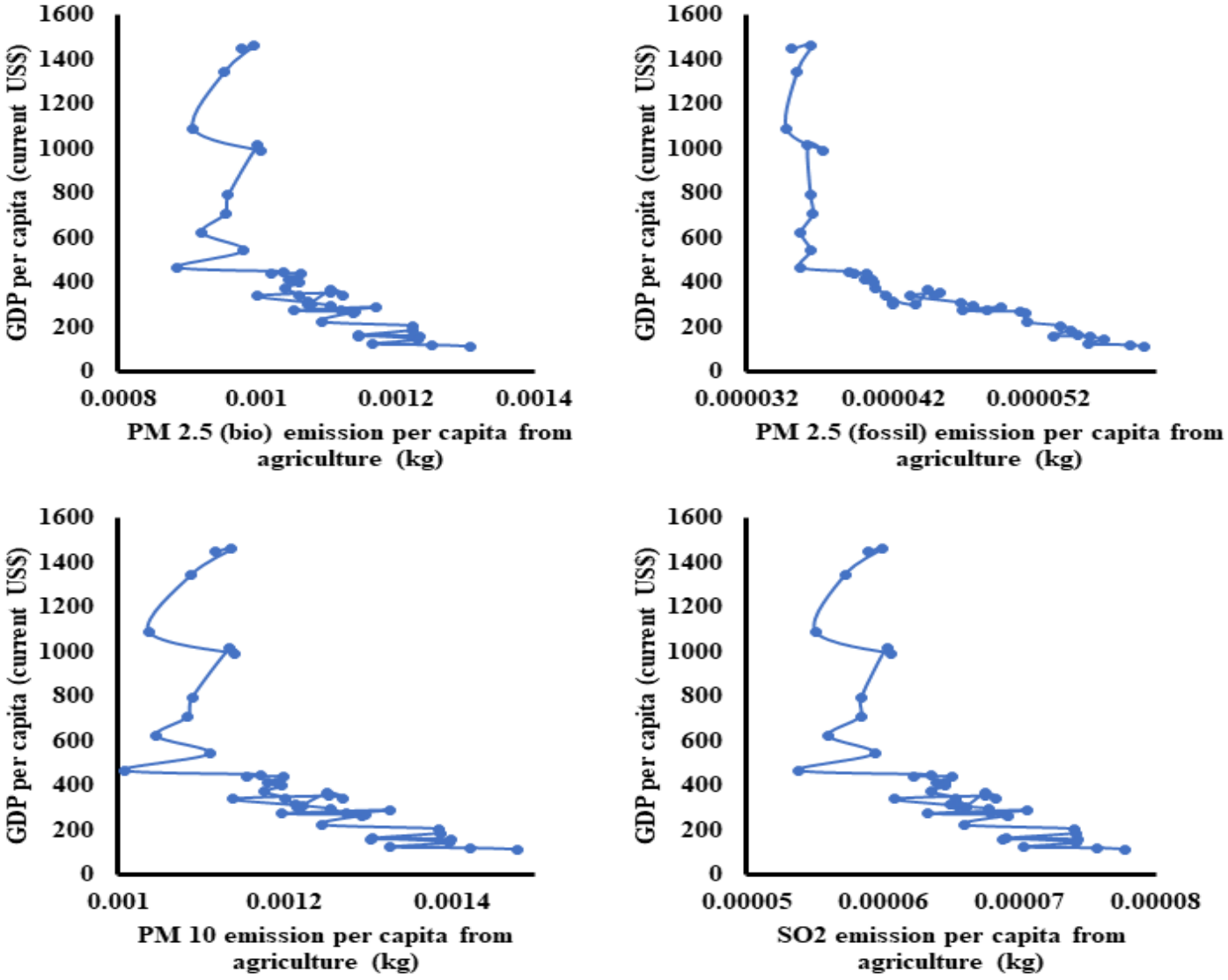


Fig 18b: Changes in emission of indicators of atmospheric pollution (per capita) from agriculture with respect to GDP per capita (current US$) in India.

(b) Doughnut economy of agriculture:

With the increase of GDP, agricultural GHG emission, arable land use and freshwater use have decreased gradually. However, the remaining 5 dimensions (i.e. ecological footprint, nitrogen and phosphorus use, synthetic fertilizer and pesticide use) have increased (figure 18a, 18b). Also, among the atmospheric pollutants, ammonia and $PM_{2.5}$ (fossil) emissions have increased. With the global level increase of GNI, similar results are found. Female employment in agriculture has decreased overall in 27 years (1991-2017). It has decreased more in the World, Central Asia and South Asia (12.57, 7.18 and 14.09%, respectively). In 27 years (1991-2017), male employment in agriculture has also decreased. It has decreased more in the World and South Asia (13.46 and 17.51%,

respectively). In 27 years (1991-2017), employment in agricultural sector has decreased more in the World and South Asia (19.1 and 15.7% respectively). Value added by agriculture has decreased in 22 years (1995-2016) in all of the regions in the world. It has decreased more in World and South Asia (4.07 and 9.27%, respectively). The relationship among the 22 indicators, through correlation and correlogram (Fig 19) has also been shown.

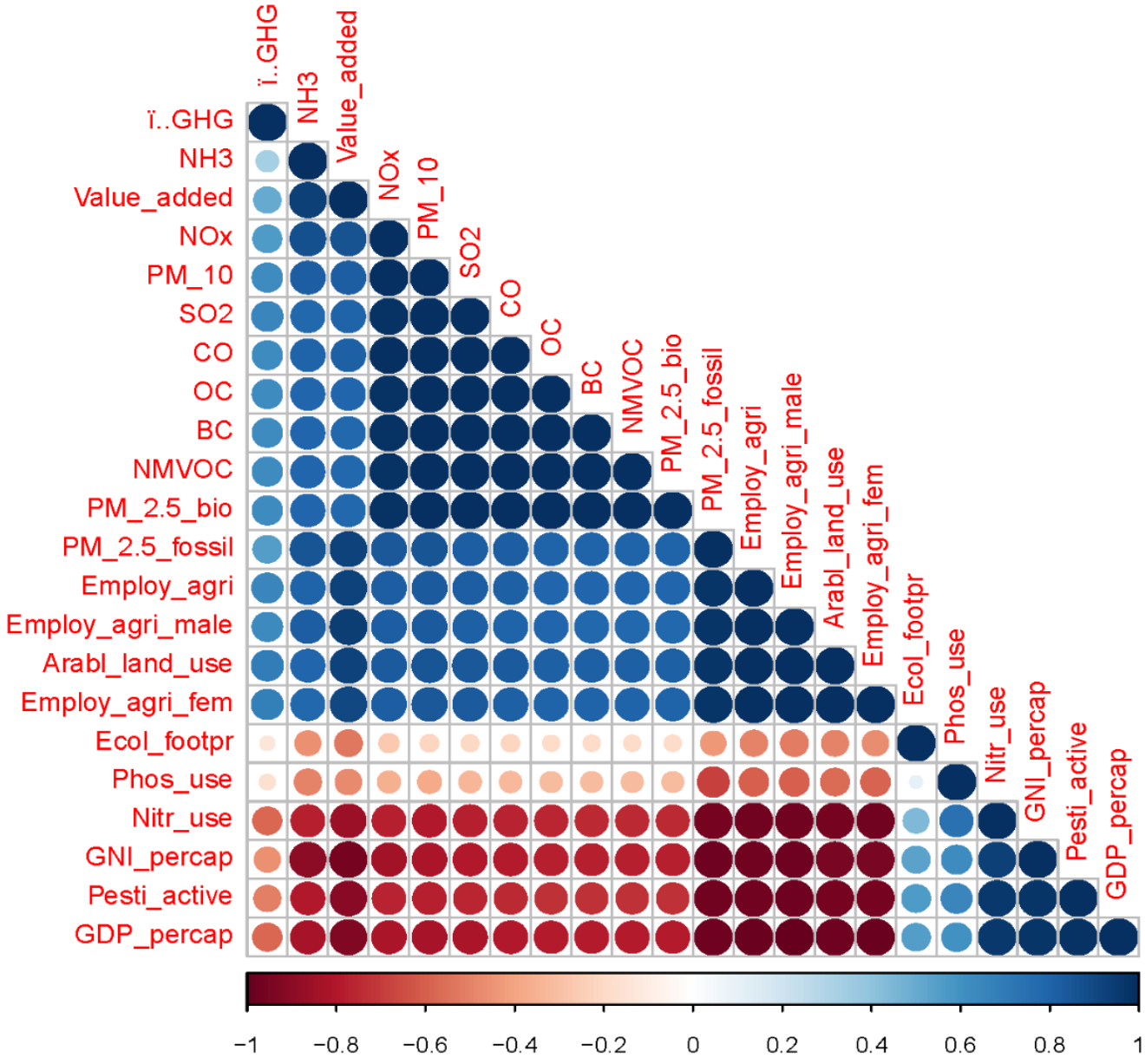


Fig 19: Correlogram of 22 indicators related to agriculture in the world. It has been done using open source software 'R'.

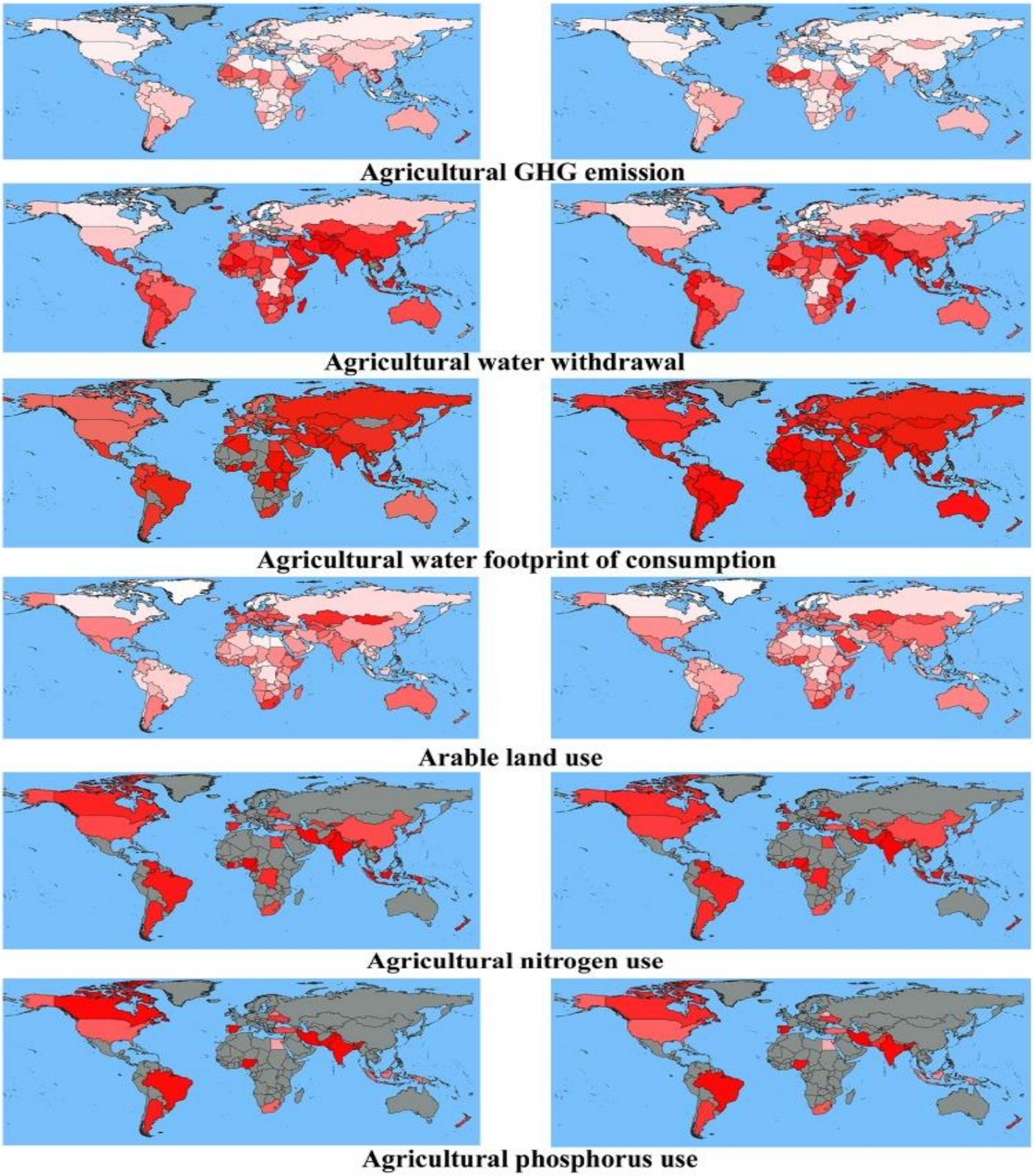


Fig 20a: Changes in the contribution of agriculture in 6 biophysical consumption dimensions related to planetary boundaries in countries of the world. A higher concentration of red indicates a higher contribution of agriculture (%) of a country. (Objective 1, 3)

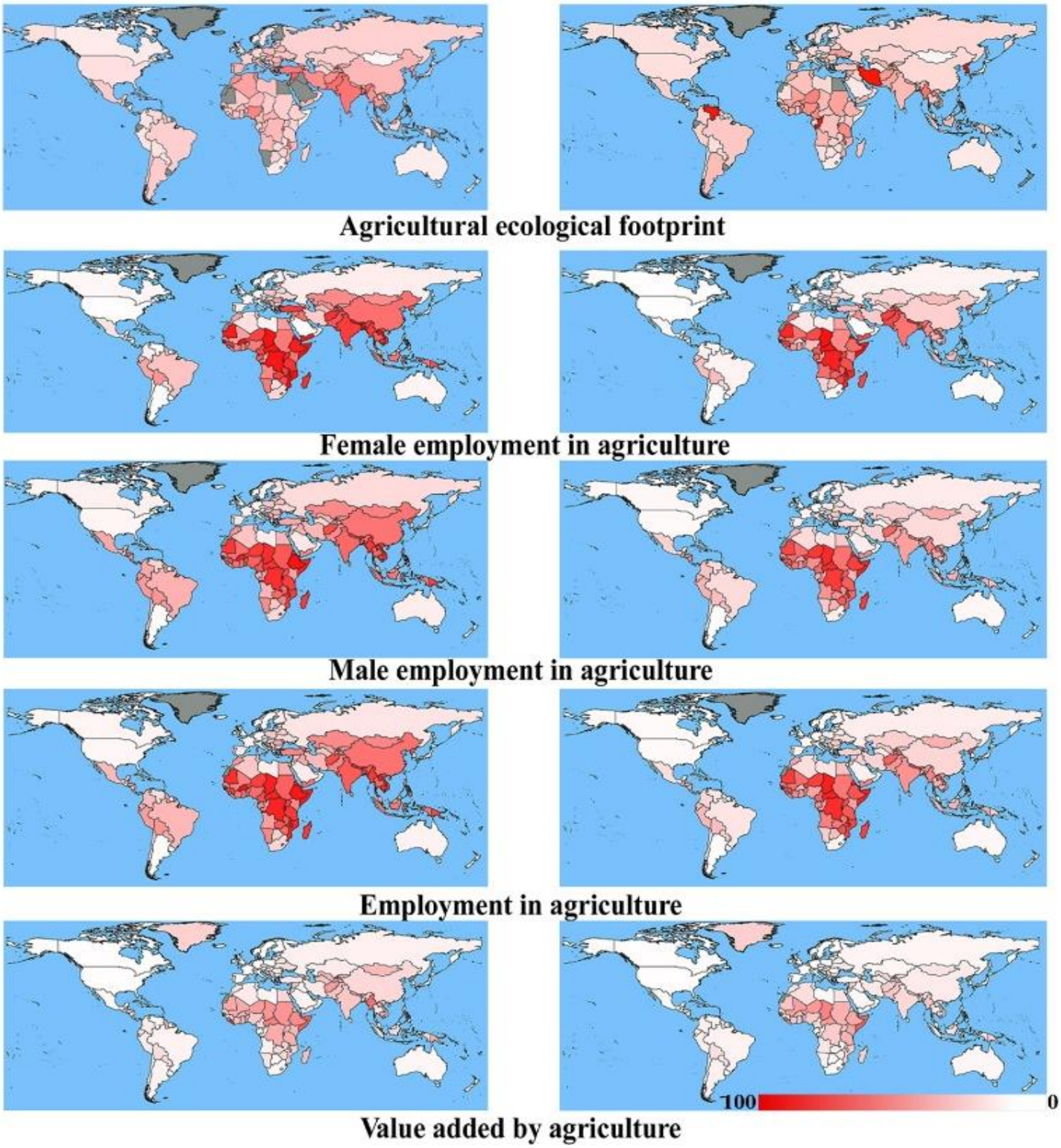


Fig 20b: Changes in the contribution of agriculture in 1 biophysical consumption dimension (first one) related to planetary boundaries and 4 socioeconomic development dimensions (next four) in countries of the world. A higher concentration of red indicates a higher contribution of agriculture (%) of a country. (Objective 1, 3)

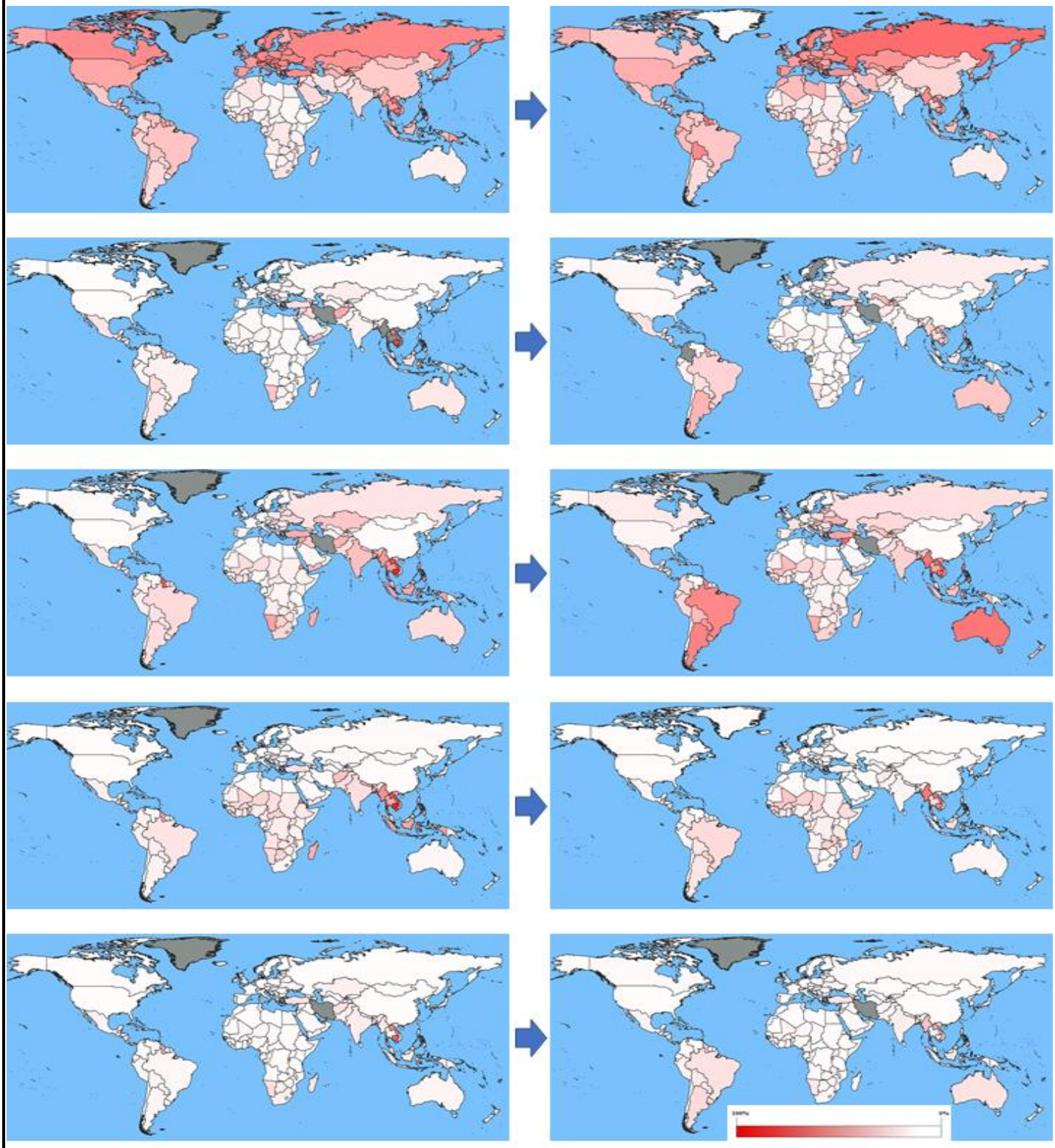


Fig 21a: Changes in the contribution of agriculture in 5 indicators of atmospheric pollution related to planetary boundaries in countries of the world (1970-2012). (Objective 1, 3)

A higher concentration of red indicates a higher contribution of agriculture (%) of a country. The indicators are – Ammonia, Black carbon, Carbon monoxide, Oxides of nitrogen and Non-methane volatile organic compounds. (Objective 1, 3)

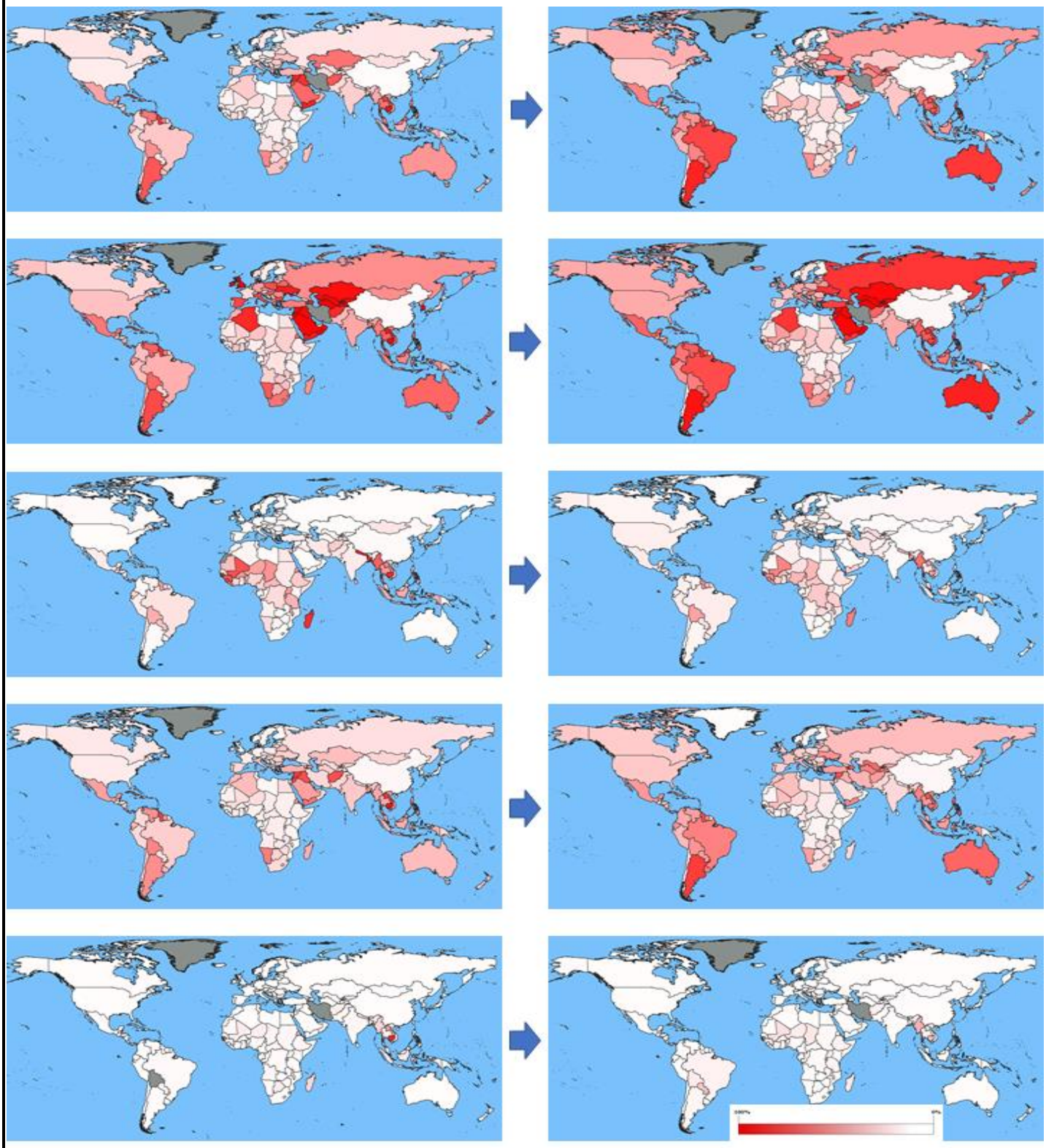


Fig 21b: Changes in the contribution of agriculture in 5 indicators of atmospheric pollution related to planetary boundaries in countries of the world (1970-2012). (Objective 1, 3)

The indicators are – Organic carbon, PM 2.5 (bio), PM 2.5 (fossil), PM 10 and Sulphur dioxide. (Objective 1, 3)

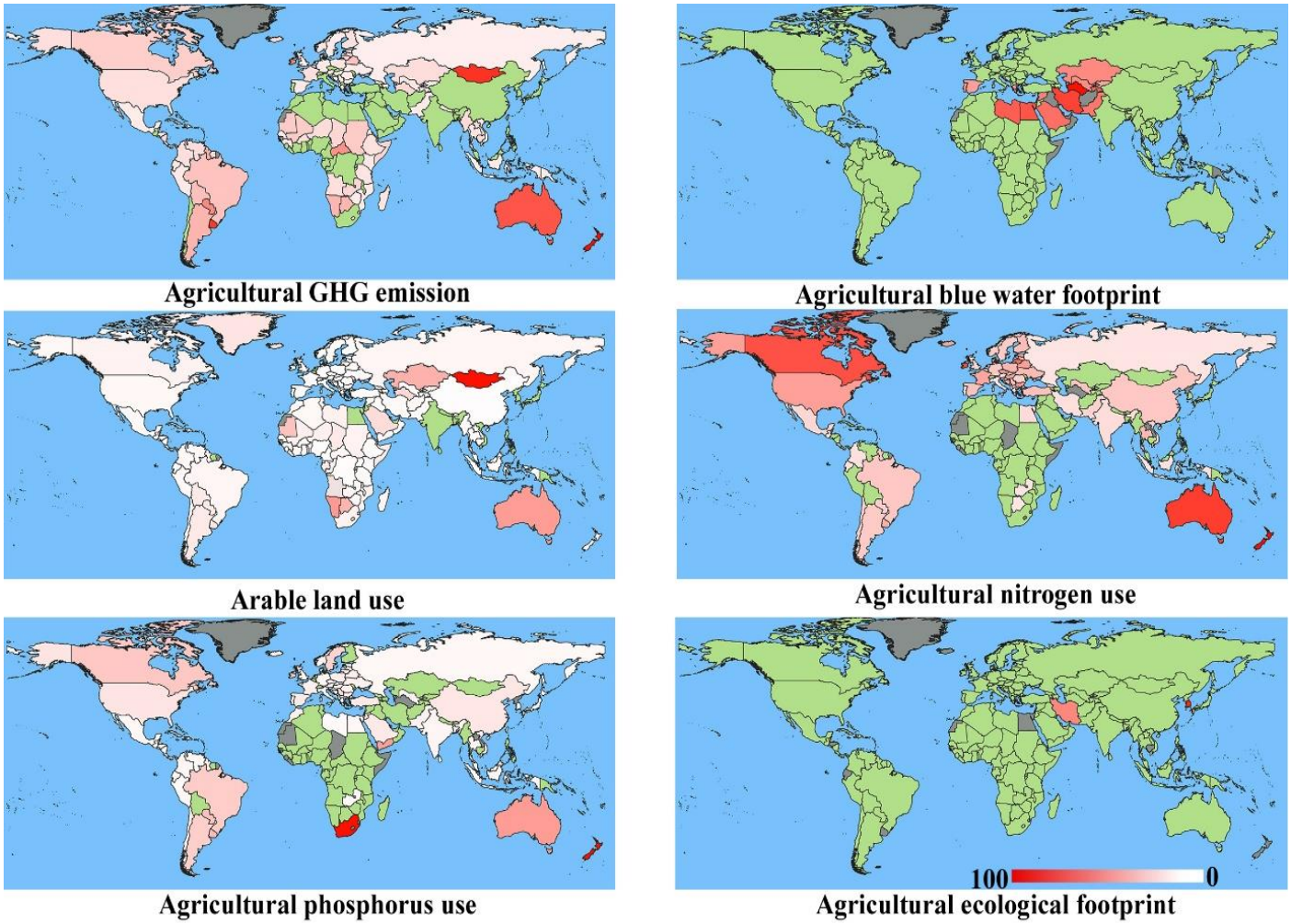


Fig 22: Recent scenario of countries in the world on 6 dimensions of biophysical consumption related to safe operating space of agriculture (i.e. planetary boundaries framework). (Objective 5, 6)

Green and red colours = countries which are within or exceeded safe limits of respective dimensions of planetary boundaries. A higher concentration of red = how far away the country is from a safe limit.

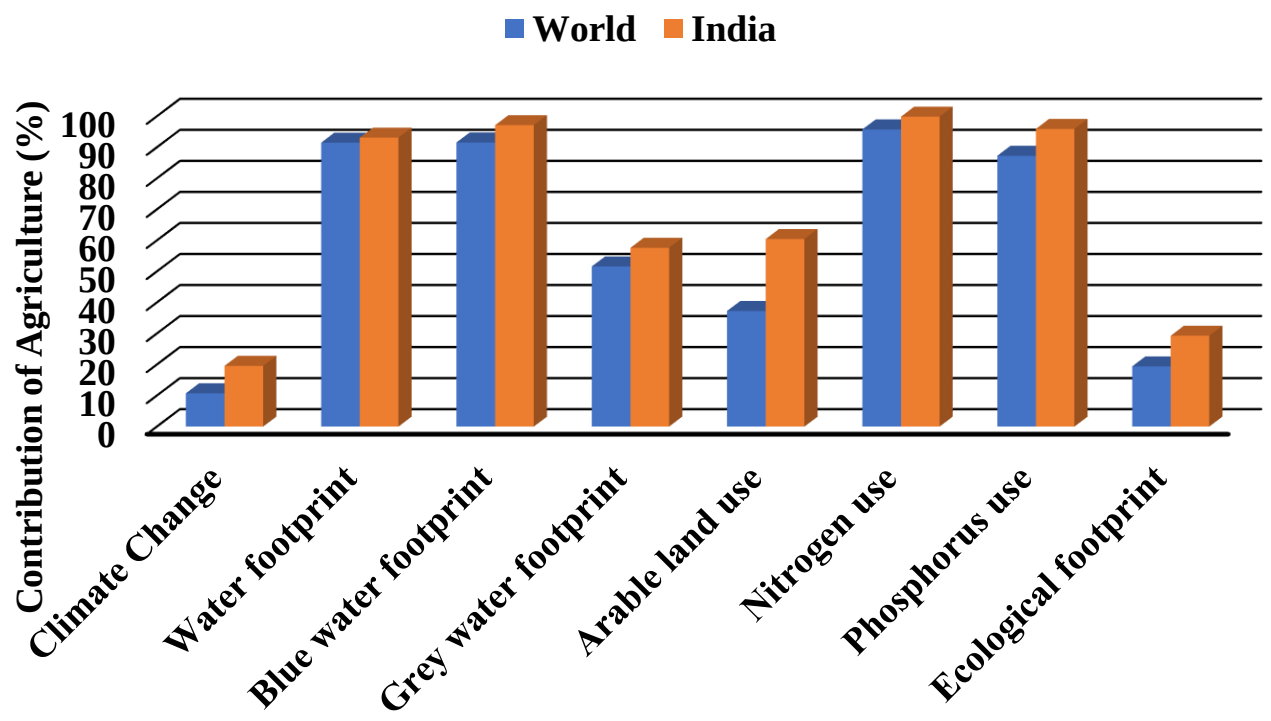


Fig 23: Contribution of agriculture in 8 biophysical resources' consumption in India and World. (Objective 5, 6)

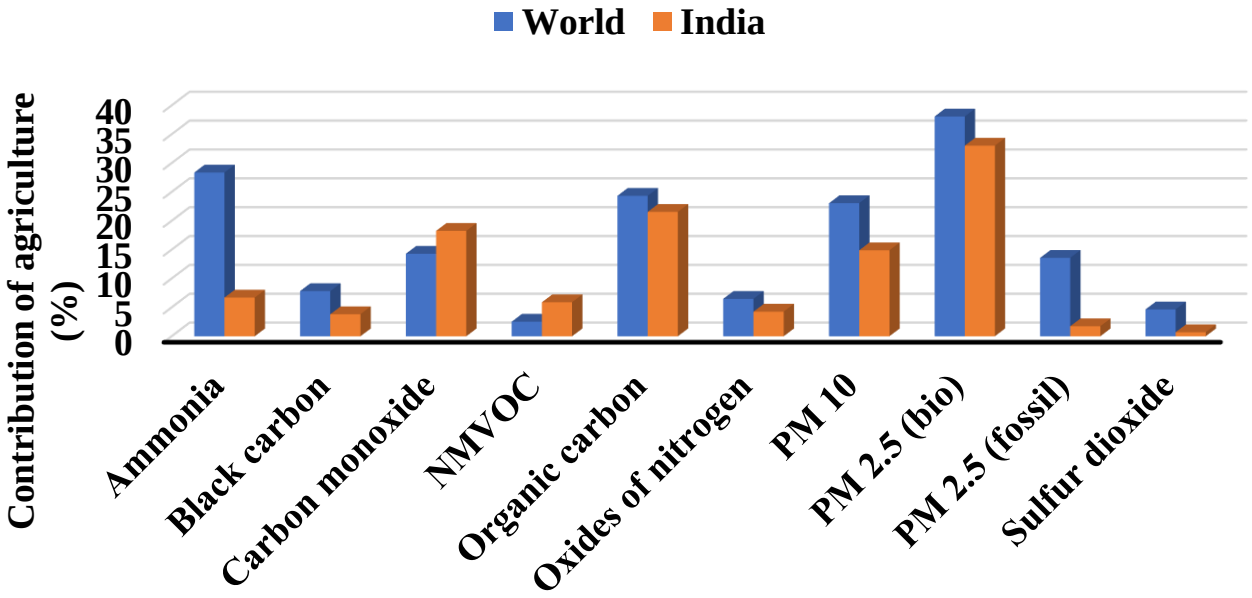


Fig 24 Contribution of agriculture in 10 dimensions of atmospheric pollution in India and World. (Objective 5, 6)

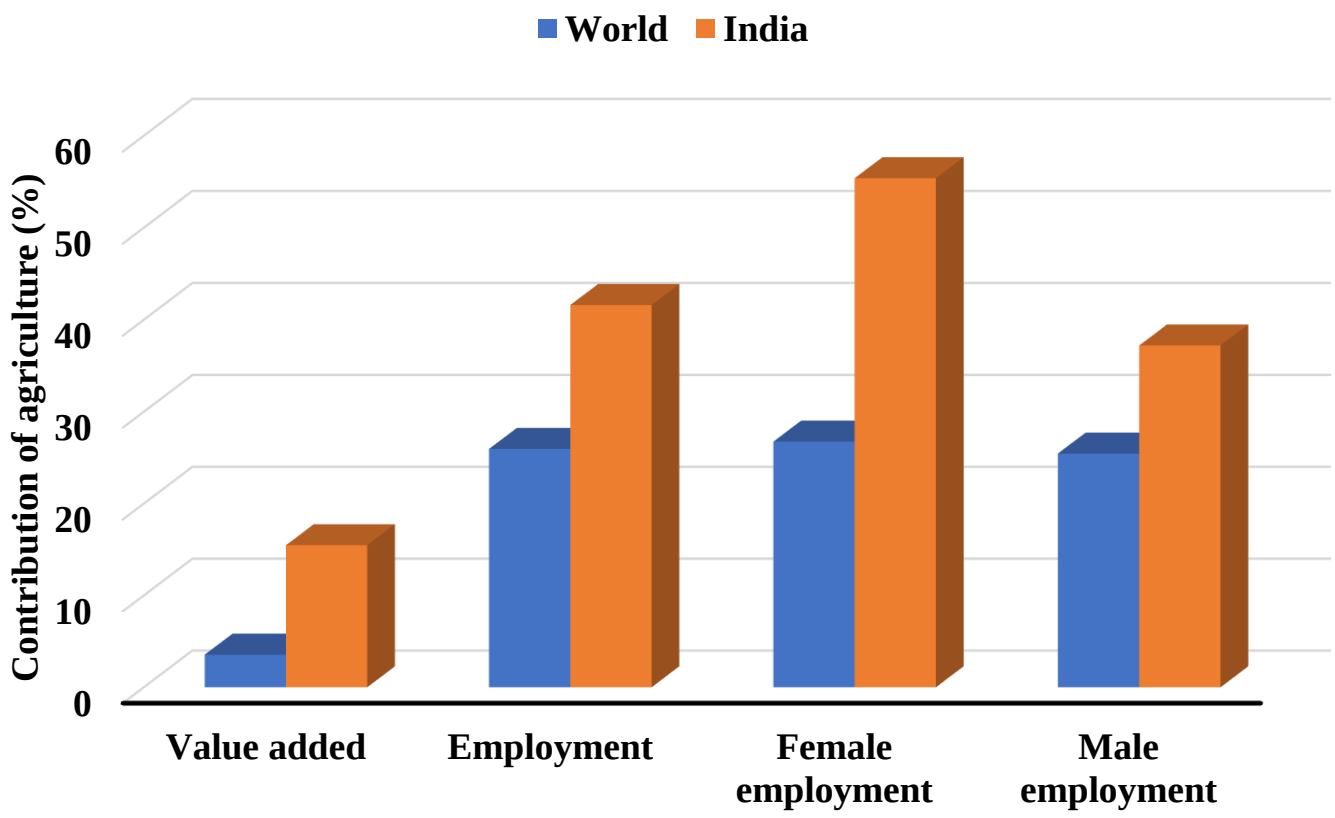


Fig 25: Contribution of agriculture in 4 dimensions of social development in India and World. (Objective 5, 6)

(c) **Future biophysical consumption in agriculture in India:**

The increase of probable biophysical resource consumption in agriculture in 2050 from present value in India can vary; like - climate change (19.56-81.52%), freshwater use (18-67.54%), arable land use (18.18-318.38%), nitrogen use (14.45% decrease to 57.95% increase), phosphorus use (18.04% decrease to 90.39% increase) and ecological footprint (3.13-58.85%) (Fig 26).

If the most efficient path of population growth is not chosen over the opposite, biophysical safe limits, related to agriculture, can decrease by almost 55% (climate change), 300% (freshwater use), 50-55% (arable land use), 180% (nitrogen use), 265% (phosphorus use) and 20% (EF) in 2050 (Figure 27).

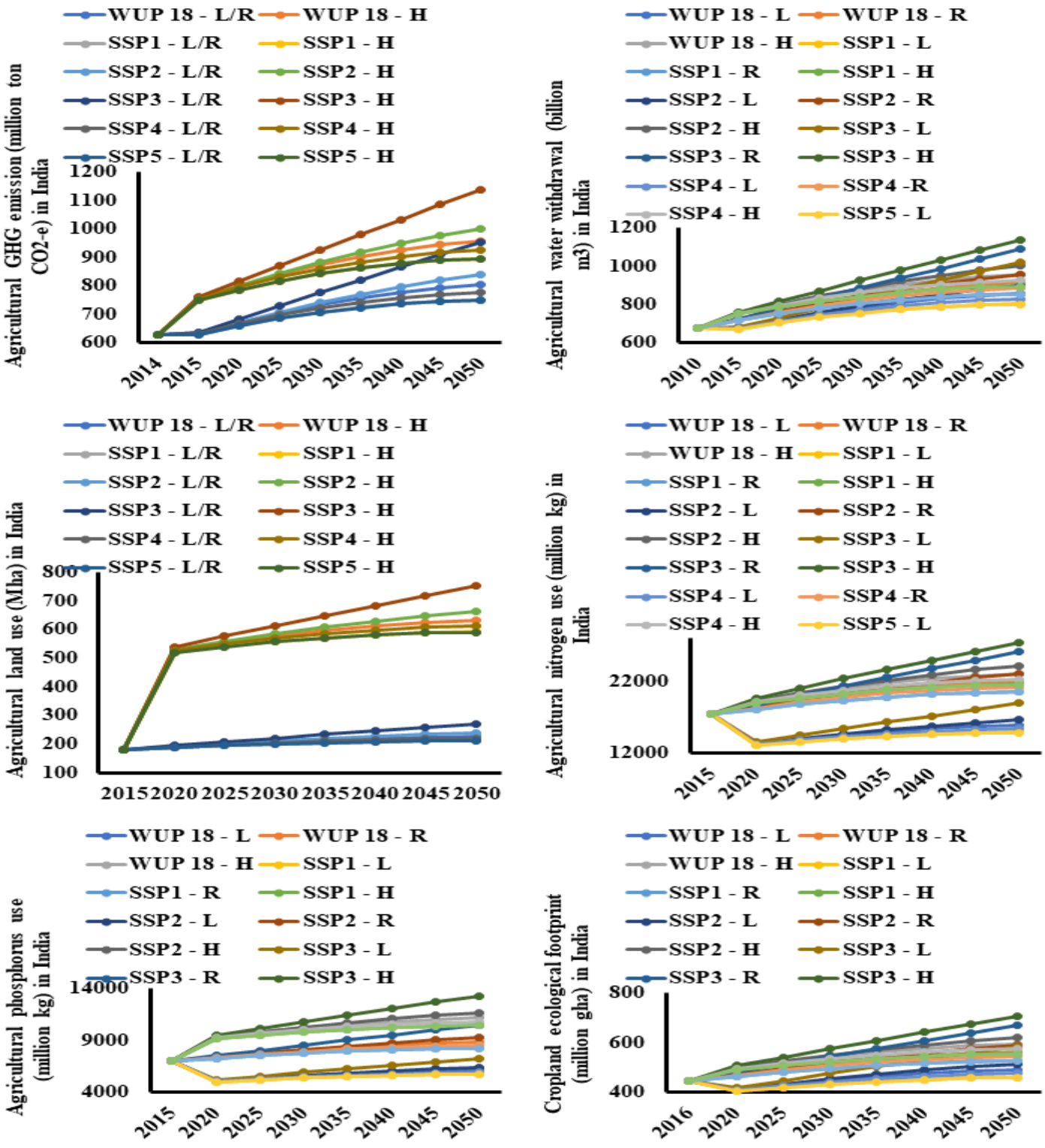


Fig 26: Projection of 6 dimensions of 6 biophysical resource consumption in Indian agriculture in future up to 2050. (Objective 2, 4)

The 6 scenarios are – 5 SSPs (shared socioeconomic pathways) and 1 UN (World Urbanization Projection, 2018). It is projected on 3 levels of consumption: lowest, recent (based on latest data availability) and highest.

If the most efficient path of population growth is not chosen over the opposite, biophysical safe limits, related to agriculture, can decrease by almost 55% (climate change), 300% (freshwater

use), 50-55% (arable land use), 180% (nitrogen use), 265% (phosphorus use) and 20% (EF) in 2050 (figure 26).

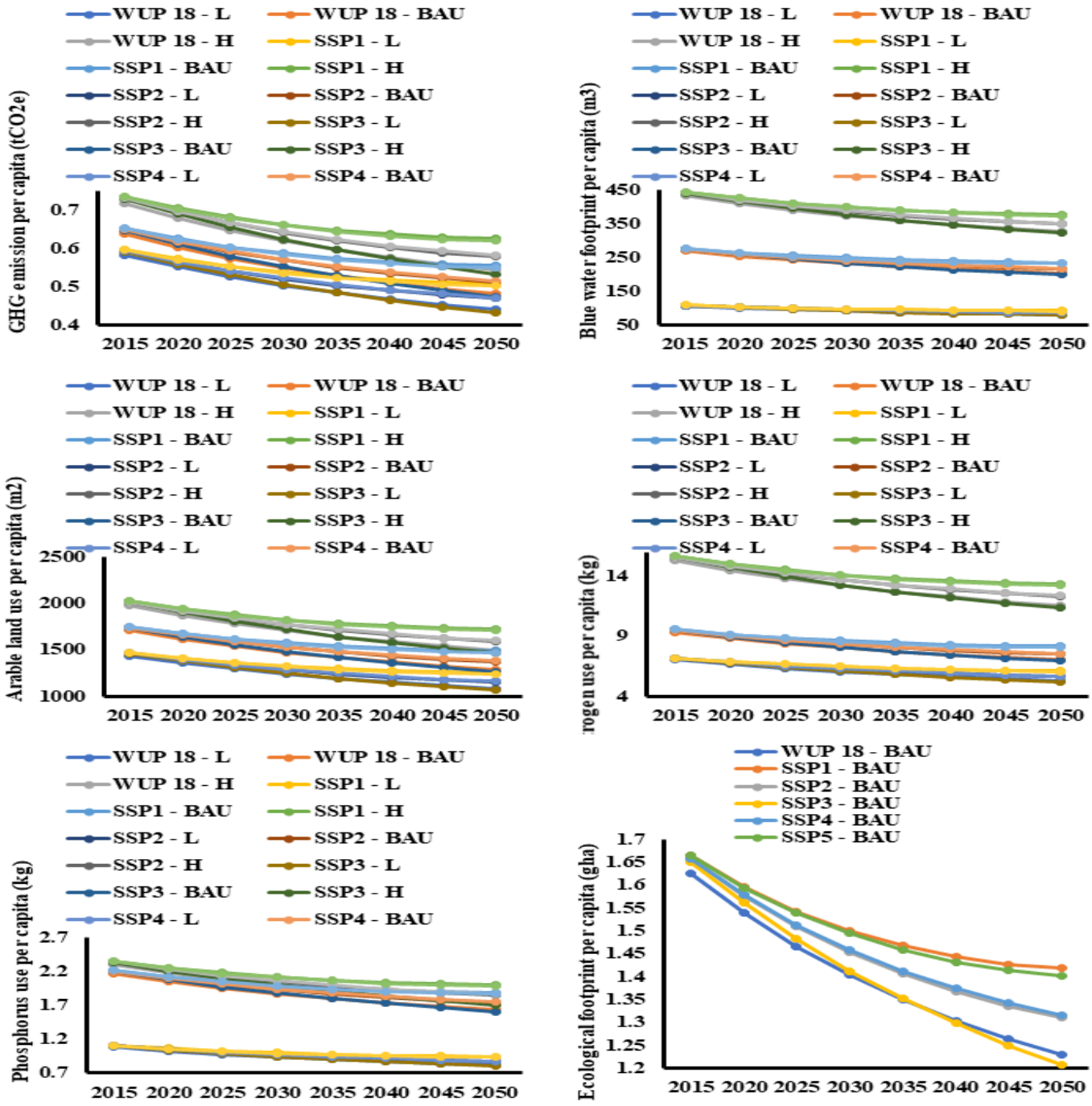

WUP 18 - L
WUP 18 - BAU
WUP 18 - H
SSP1 - L
SSP1 - BAU
SSP1 - H
SSP2 - L
SSP2 - BAU
SSP2 - H
SSP3 - L
SSP3 - BAU
SSP3 - H
SSP4 - L
SSP4 - BAU
GHG emission per capita (tCO2e)
Blue water footprint per capita (m3)
Arable land use per capita (m2)
Nitrogen use per capita (kg)
Phosphorus use per capita (kg)
Ecological footprint per capita (gha)
SSP5 - BAU
2015 2020 2025 2030 2035 2040 2045 2050

Fig 27: Projection of availability of 6 biophysical resources for agriculture up to 2050 in the world. Based on 5 SSPs and 1 WUP 2018 projection. (Objective 2, 4)

The 6 scenarios are – 5 SSPs (shared socioeconomic pathways) and 1 UN (World Urbanization Projection, 2018). It is projected on 3 levels of consumption: lowest, BAU (based on latest data availability) and highest.

Chapter 4

Water and Land Gap of Agriculture in India

Water Gap:

Methodology: We have calculated the total water requirement for all major agricultural products for food consumption in India in 3 steps, which are explained in fig 28 and the sources of data used are in table 16.

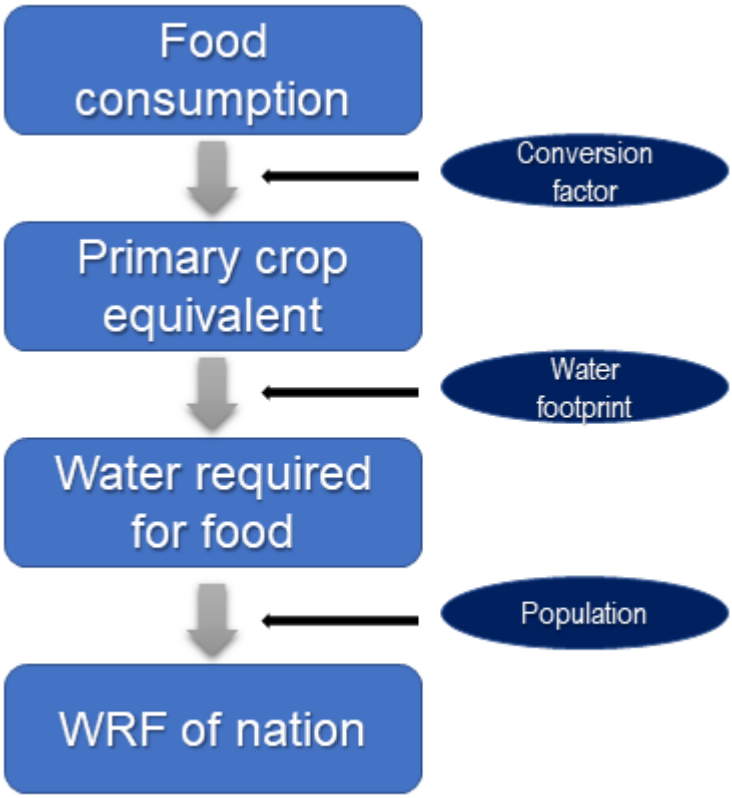


Fig 28: Flow chart of the calculations flow to link food consumption with water requirement for food (WRF).

Table 16: Data used and their source for calculation of water requirement for food of India.

No.	Indicators	Data Sources
1	Food consumption	Food Balance Sheet (FBS), FAO
2	Conversion factors	Nutritive Factors, FAO
3	Water footprint	WaterStat
4	Population	FAOSTAT

Results: We have analysed the water requirement of agricultural products for food consumption (1996-2013) and categorized it into food groups (Fig. 29-32).

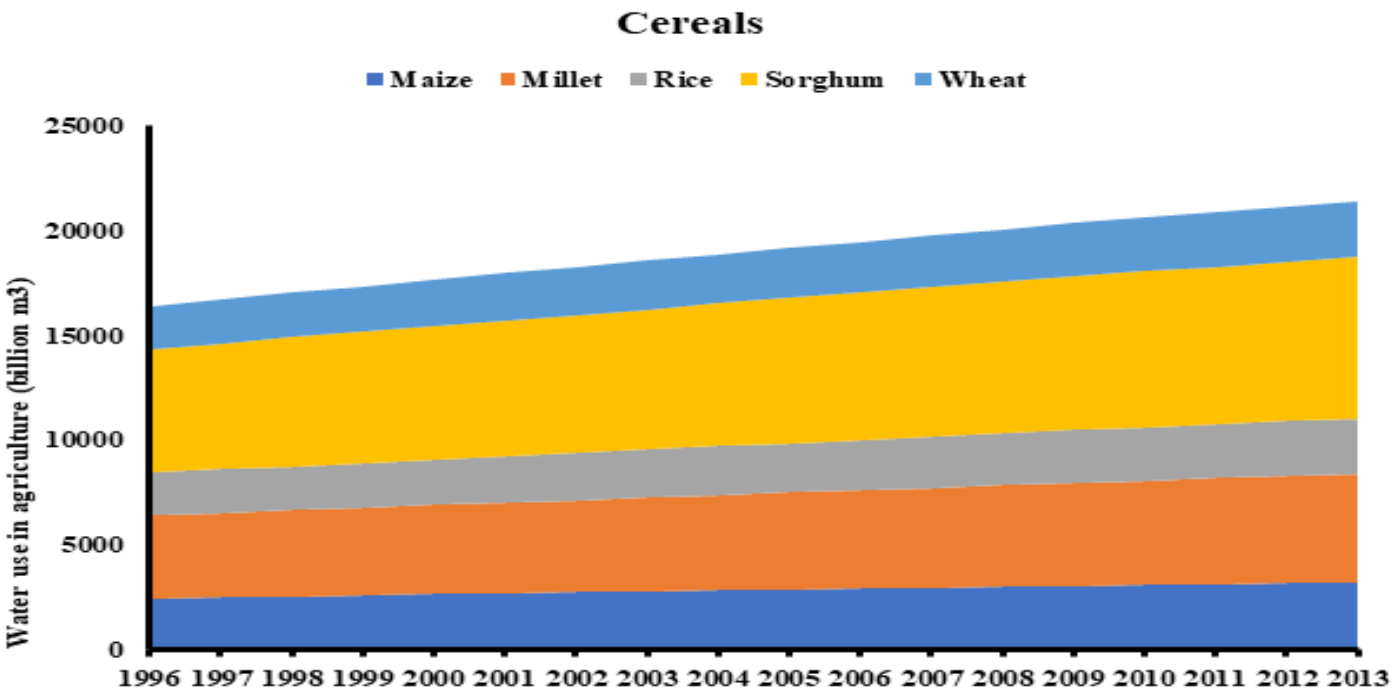


Fig 29: Water requirement for cereal consumption (WRF) in India (1996-2013). (Objective 1, 3)

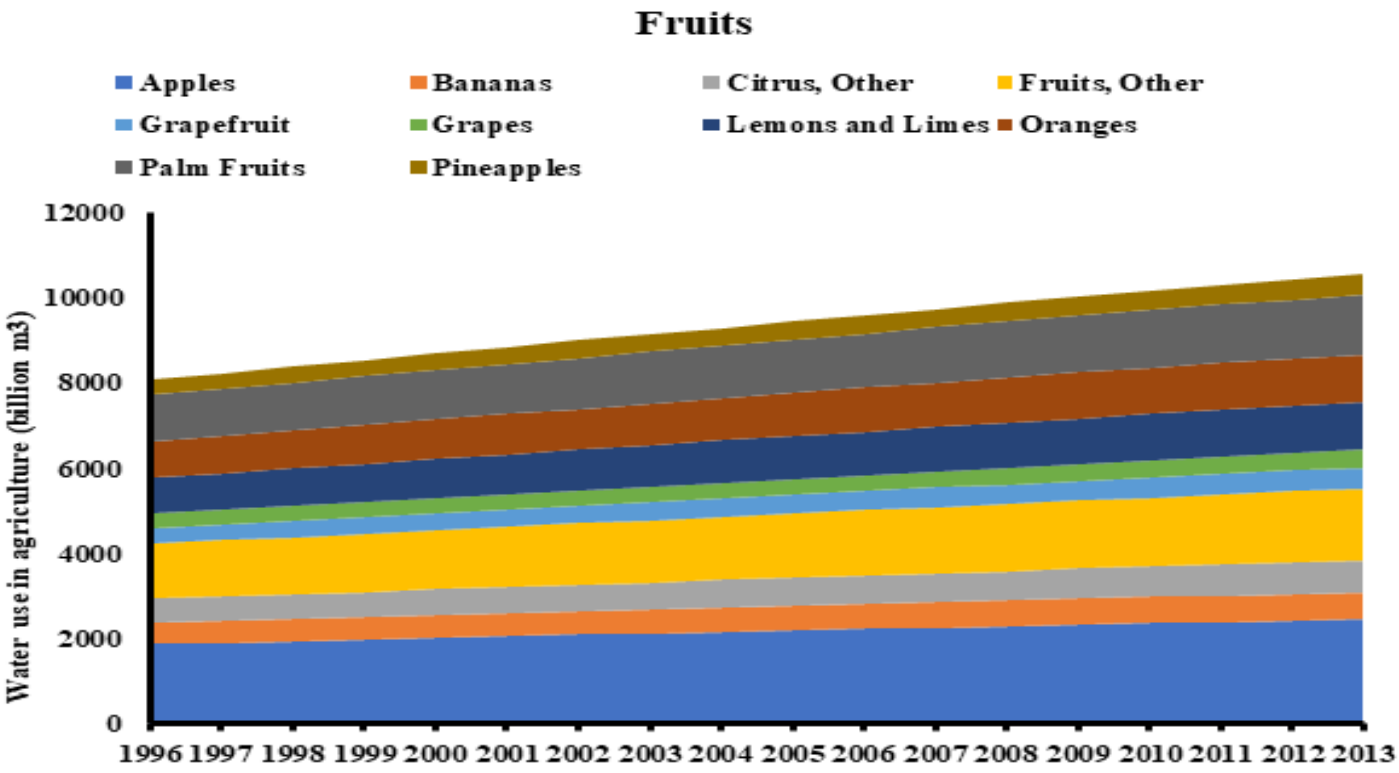


Fig 30: Water requirement for fruit consumption (WRF) in India (1996-2013). (Objective 1, 3)

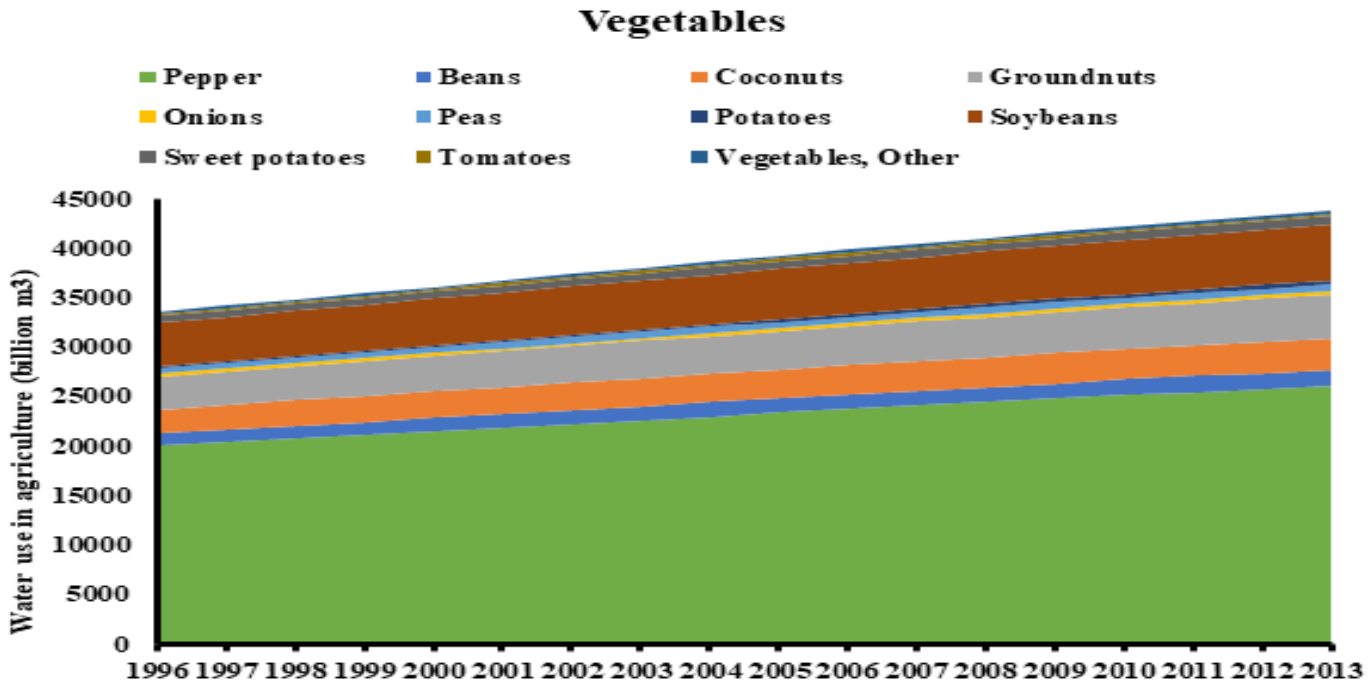


Fig 31: Water requirement for vegetable consumption (WRF) in India (1996-2013). (Objective 1, 3)

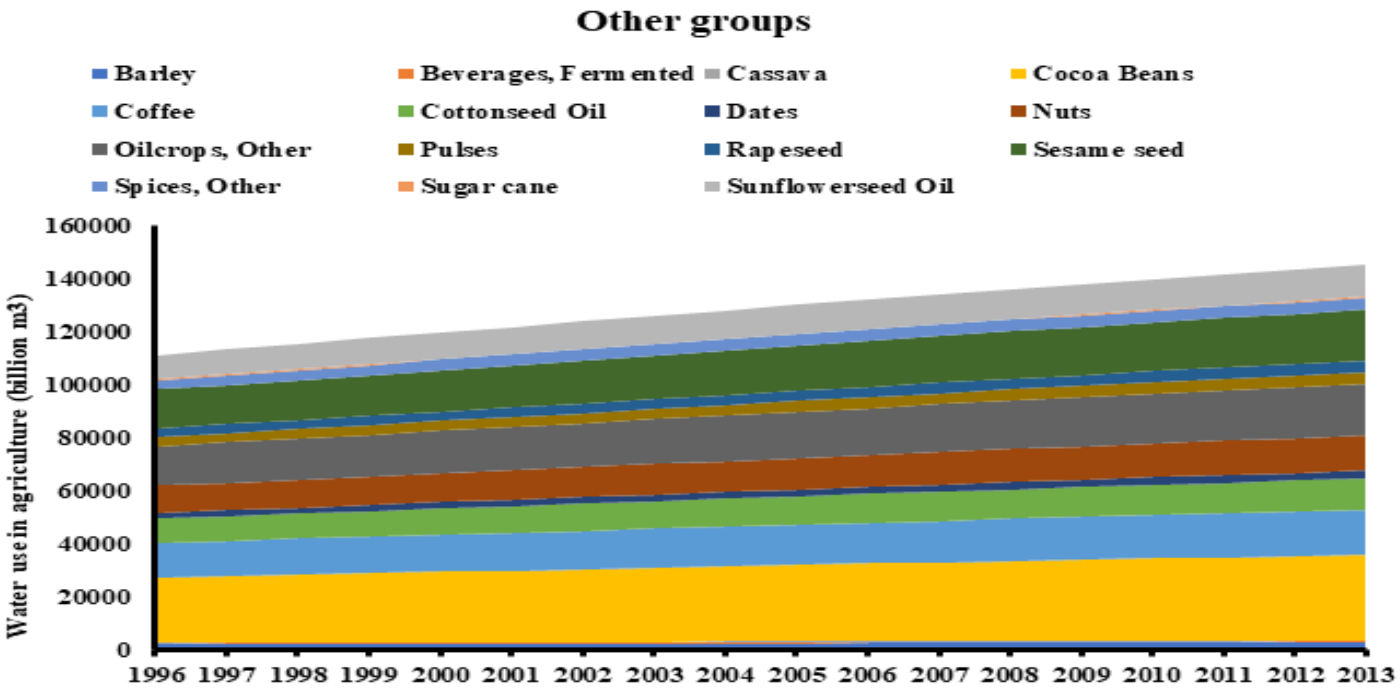


Fig 32: Water requirement for other food consumption (WRF) in India (1996-2013). (Objective 1, 3)

Future Scenarios: We have calculated land requirement of each agricultural product based on low, high and recent rate of food consumption which are then projected according to 5 SSPs and 1 UN projection scenario. Finally, these are categorized into separate food groups (Fig. 33-38).

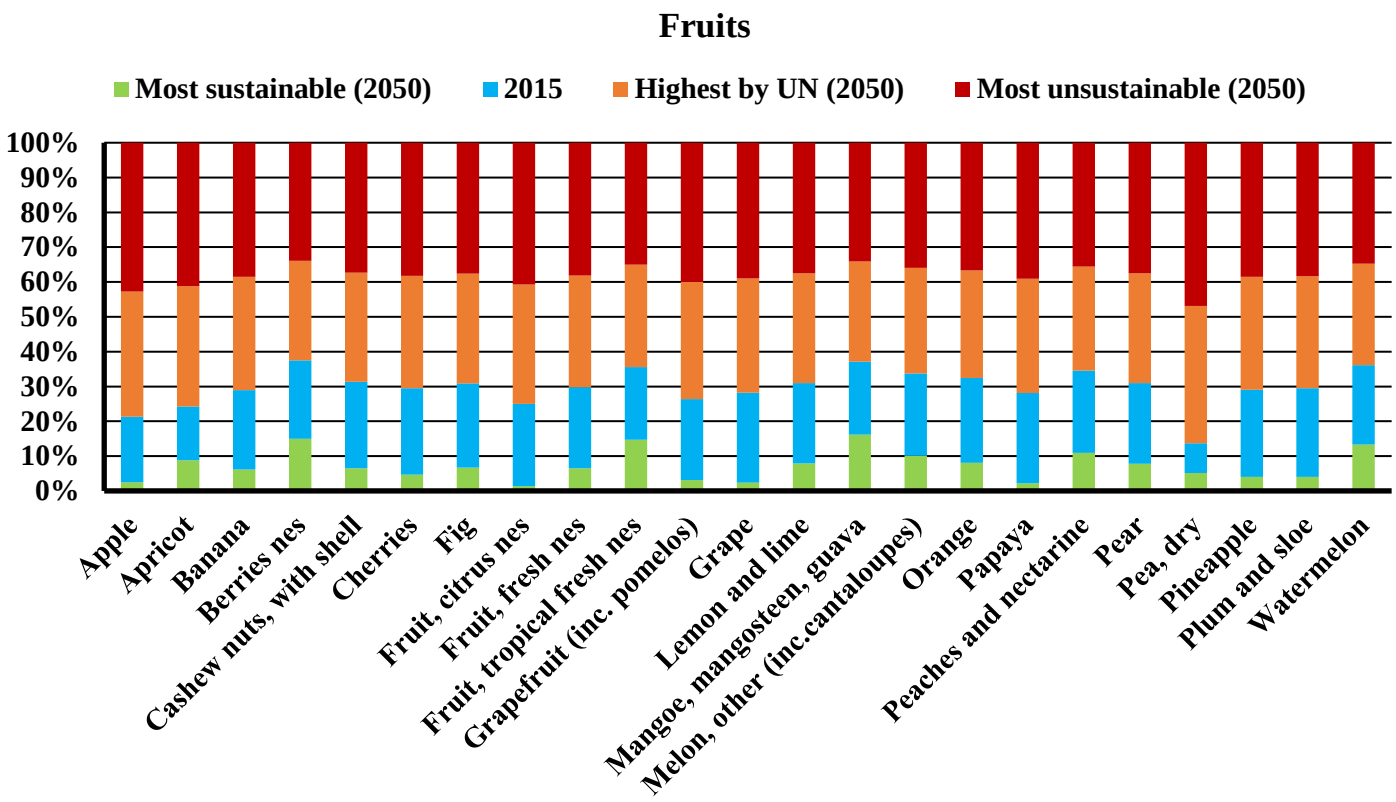


Fig 33: Water gap (2015 vs. 2050) in consumption of fruits in India. (Objective 2, 4)

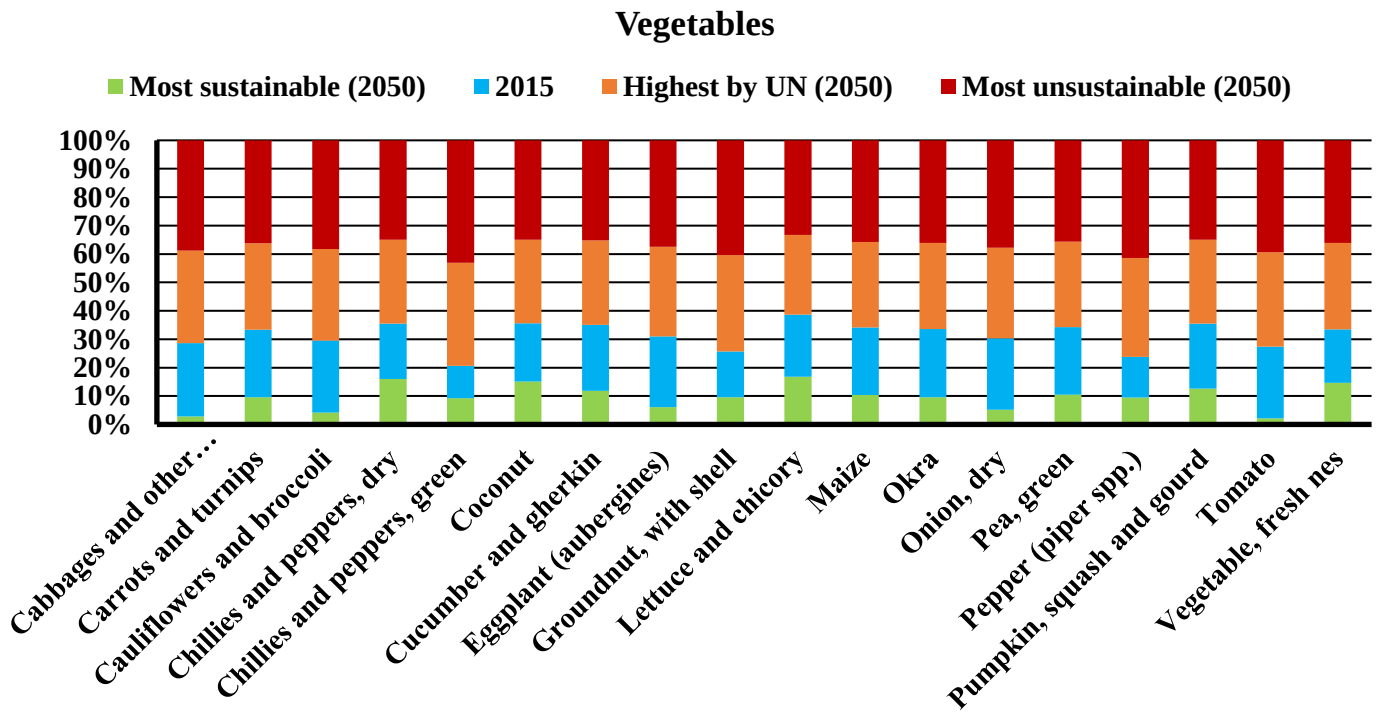


Fig 34: Water gap (2015 vs. 2050) in consumption of vegetables in India. (Objective 2, 4)

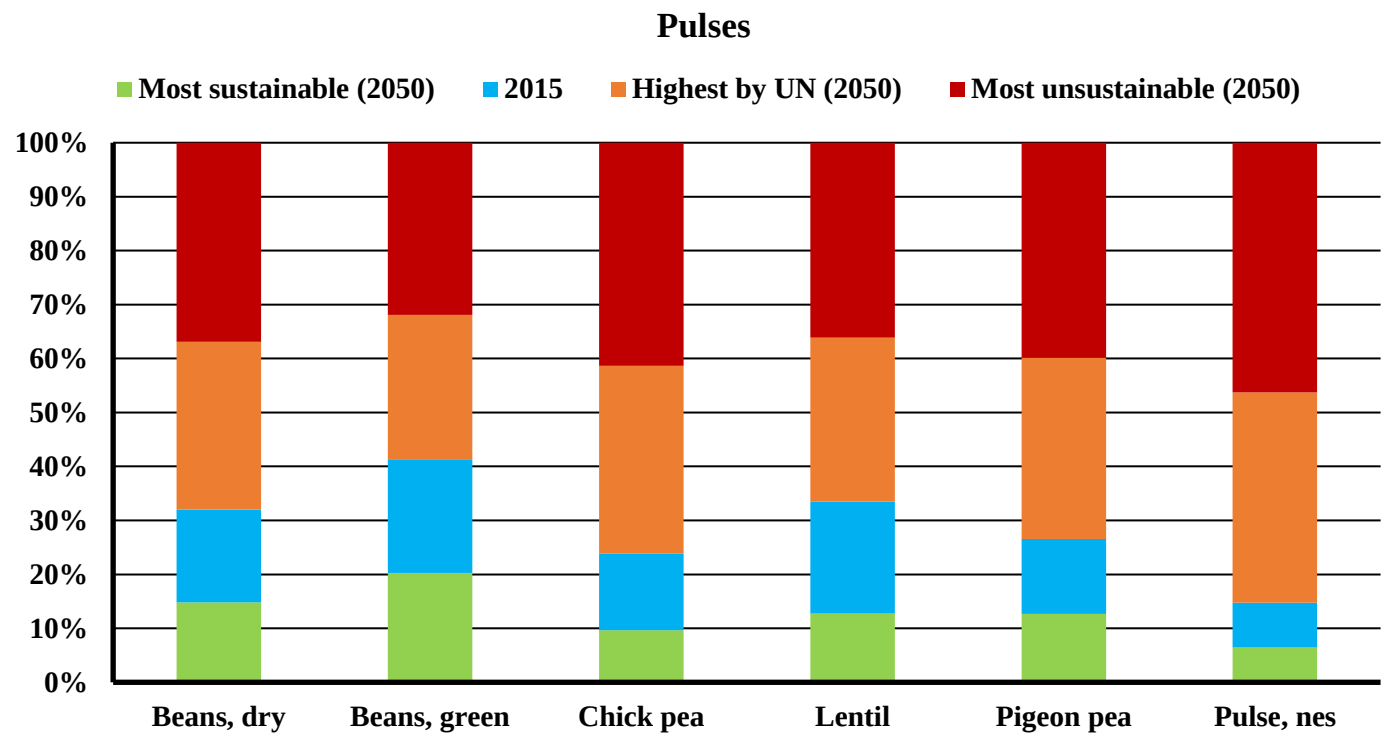


Fig 35: Water gap (2015 vs. 2050) in consumption of pules in India. (Objective 2, 4)

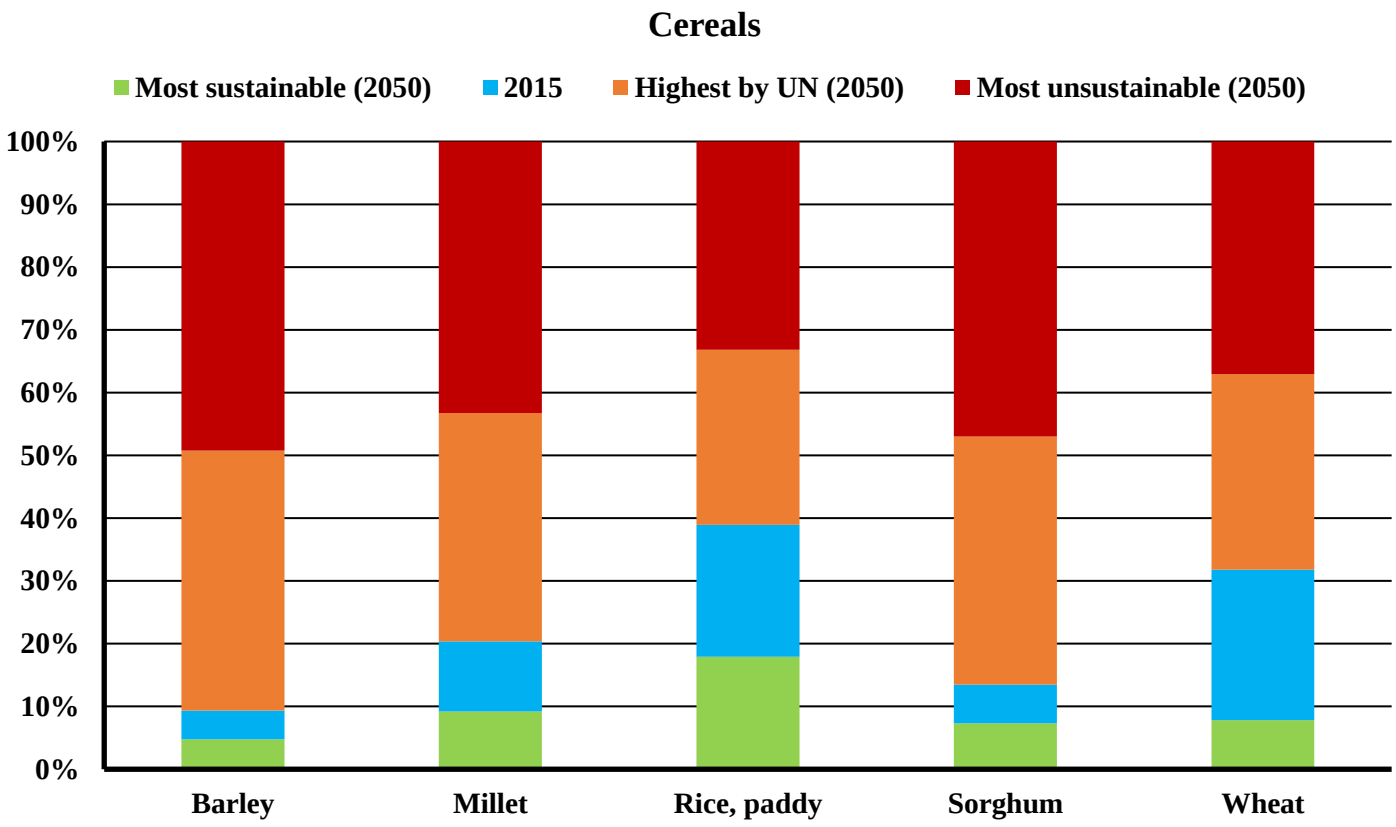


Fig 36: Water gap (2015 vs. 2050) in consumption of cereals in India. (Objective 2, 4)

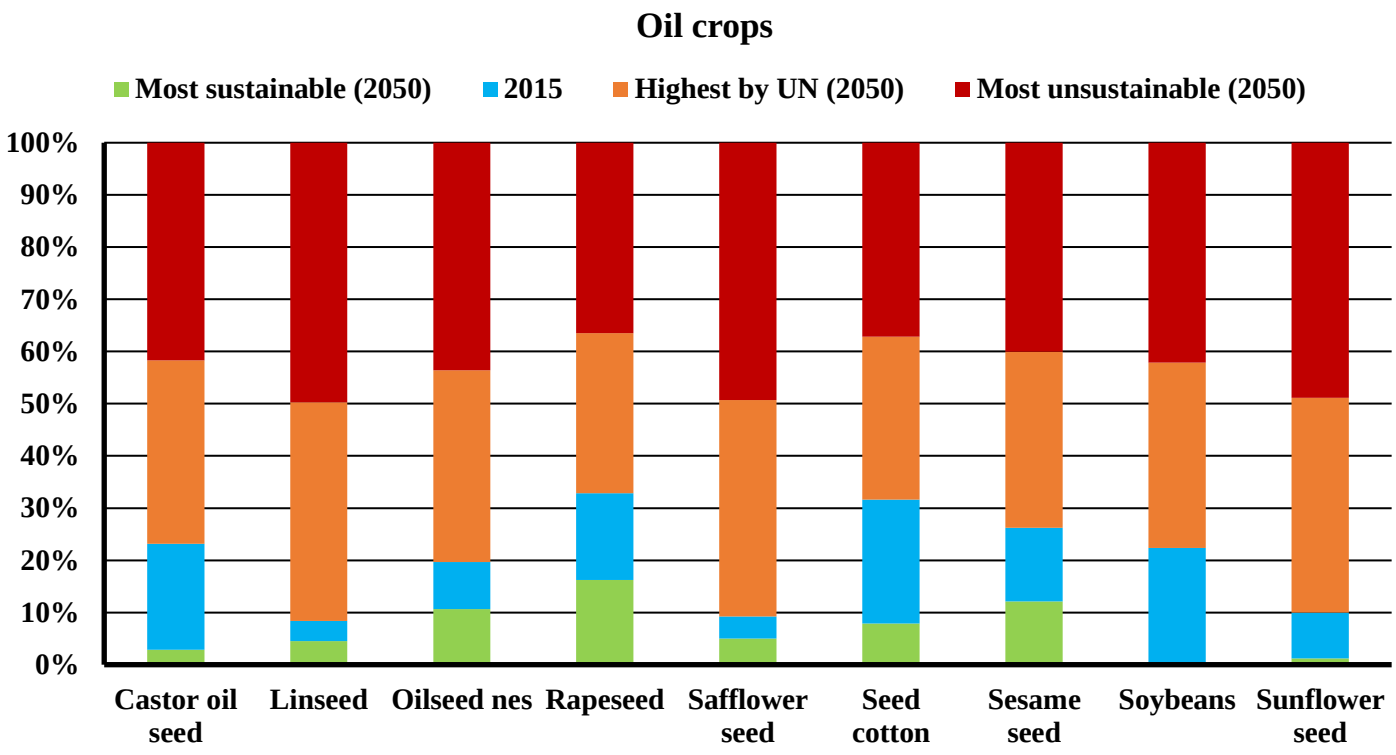


Fig 37: Water gap (2015 vs. 2050) in consumption of oil crops in India. (Objective 2, 4)

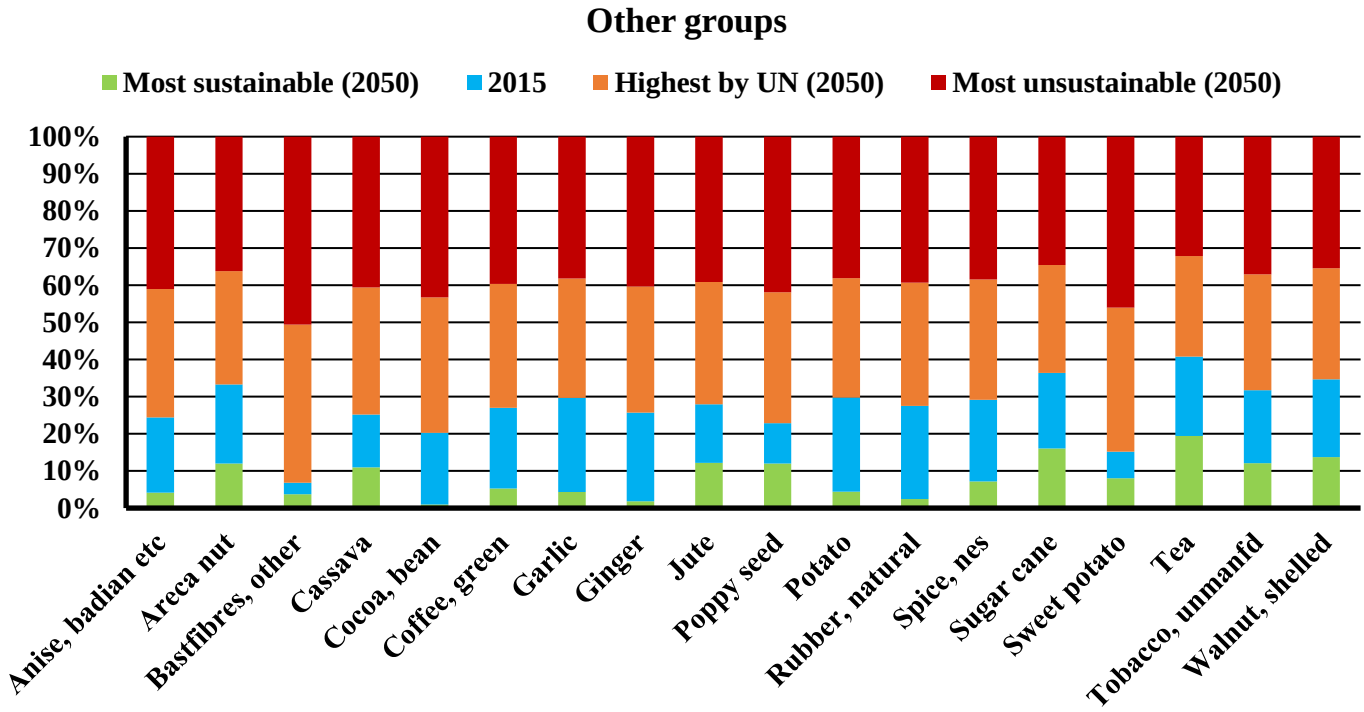


Fig 38: Water gap (2015 vs. 2050) in consumption of other food groups (vegetal) in India. (Objective 2, 4)

Land Gap:

Methodology: We have calculated the total land requirement for all major agricultural products for food consumption in India in 4 steps, which are explained in fig 39 and the sources of data used are in table 17.

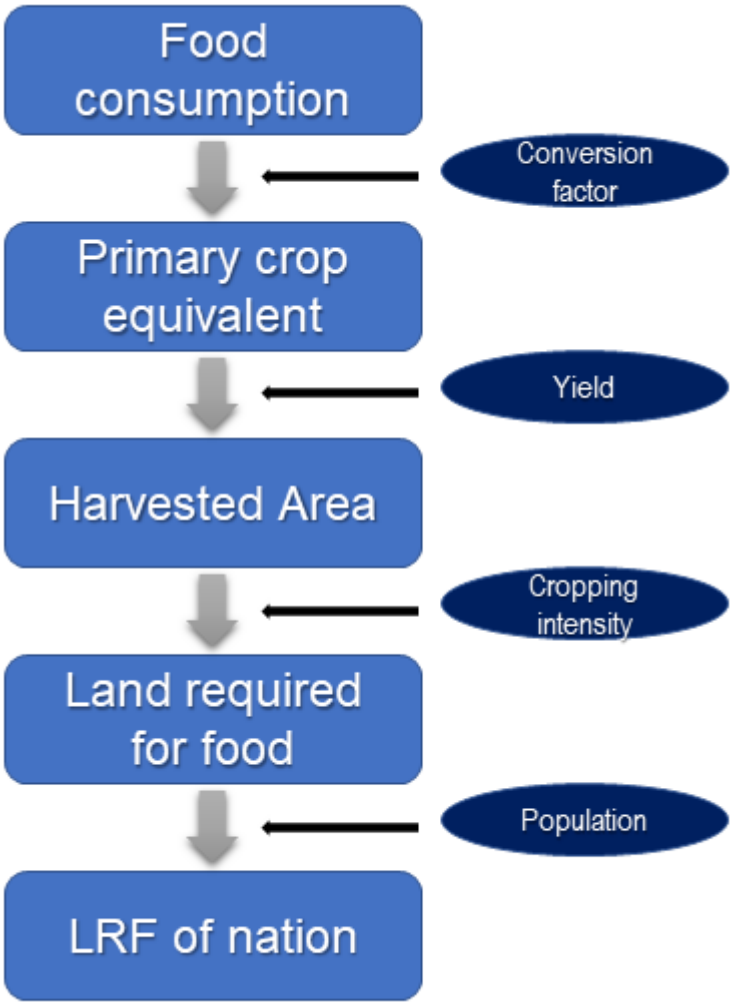


Fig 39: Flow chart of the calculations flow to link food consumption with land requirement for food (LRF).

Table 17: Data used and their source for calculation of land requirement for food of India.

No.	Indicators	Data Sources
1	Food consumption	Food Balance Sheet (FBS), FAO
2	Conversion factors	Nutritive Factors, FAO
3	Yield	FAO (in absence of national yield data, global average yield has been used)
4	Population	FAO

Results: We have analysed the land requirement of agricultural products for food consumption (1961-2013) and categorized it into food groups (Fig. 40a-40b).

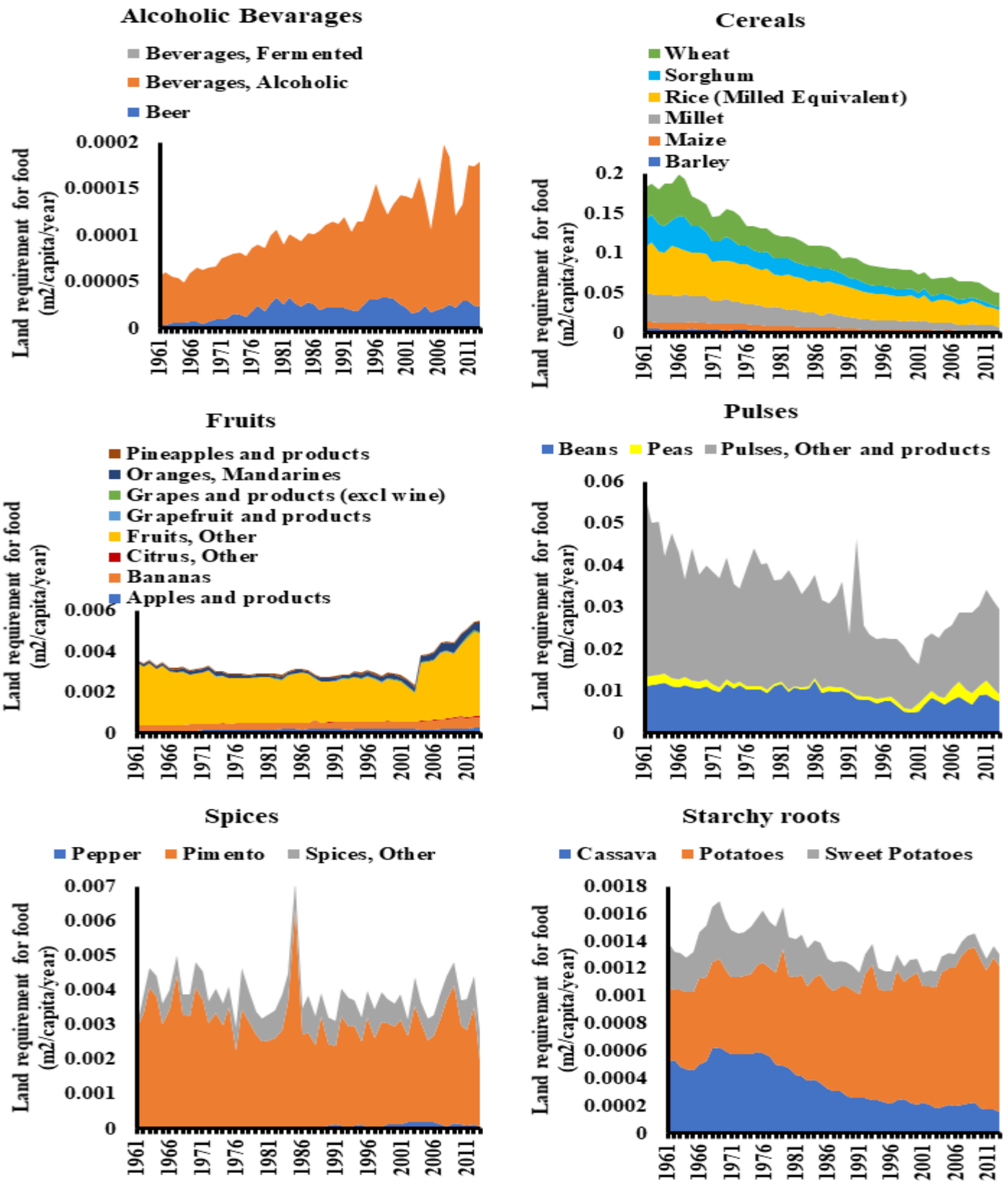


Fig 40a: Land required (m^2 $capita^{-1}$ $year^{-1}$) for 6 food groups (of agricultural origin) in India (1961-2013). (Objective 1, 3) These food groups are – (1) Alcoholic beverages, (2) Cereals, (3) Fruits, (4) Pulses, (5) Spices and (6) Starchy roots.

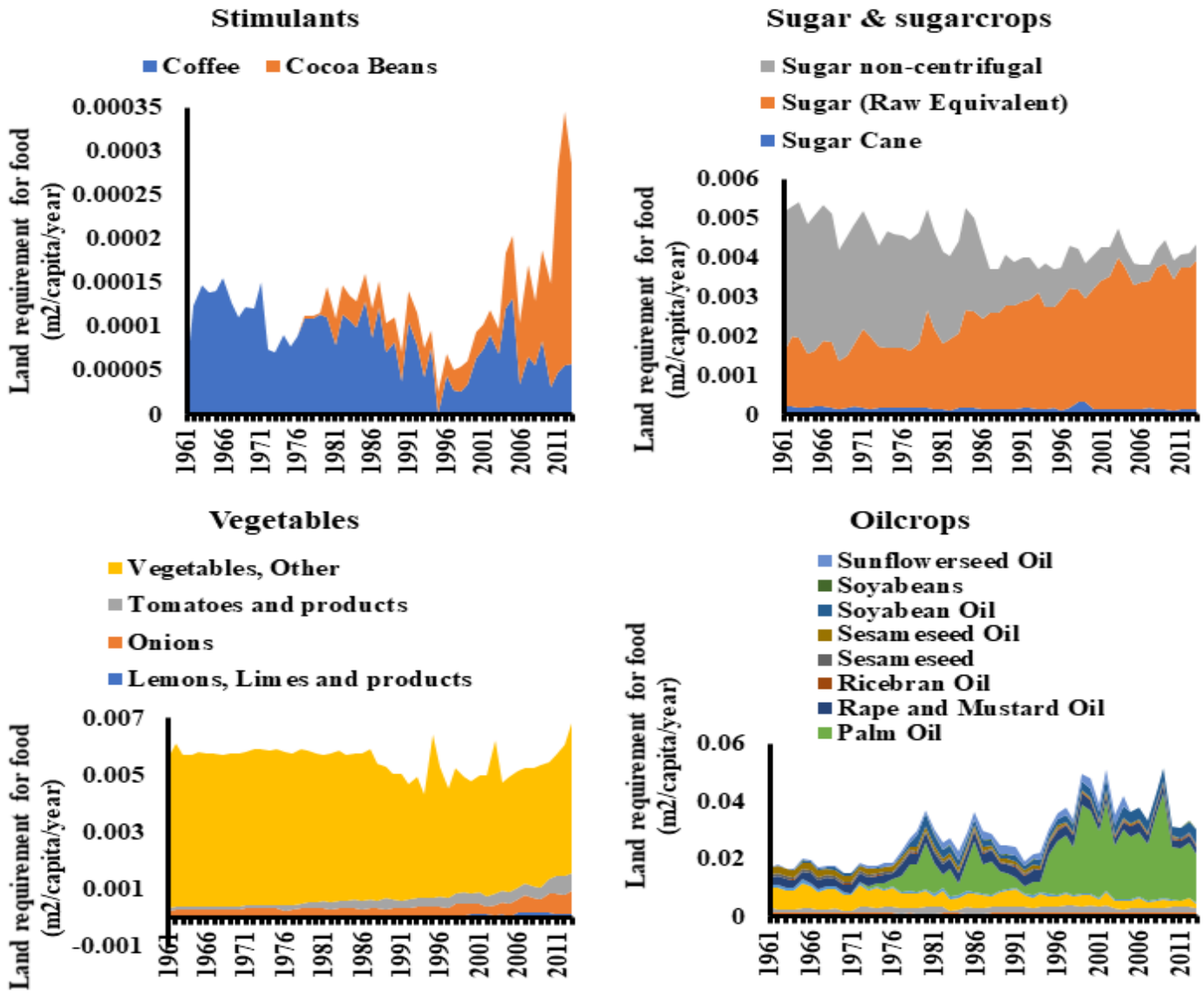


Fig 40b: Land required (m^2 $capita^{-1}$ $year^{-1}$) for 4 food groups (of agricultural origin) in India (1961-2013). (Objective 1, 3) These food groups are – (1) Stimulant crops, (2) Sugar crops, (3) Vegetables and (4) Oil crops.

Future Scenarios: We have calculated land requirement of each agricultural product based on low, high and recent rate of food consumption which are then projected according to 5 SSP and 1 UN projection scenario. Finally, these are categorized into separate food groups (Fig. 41-45).

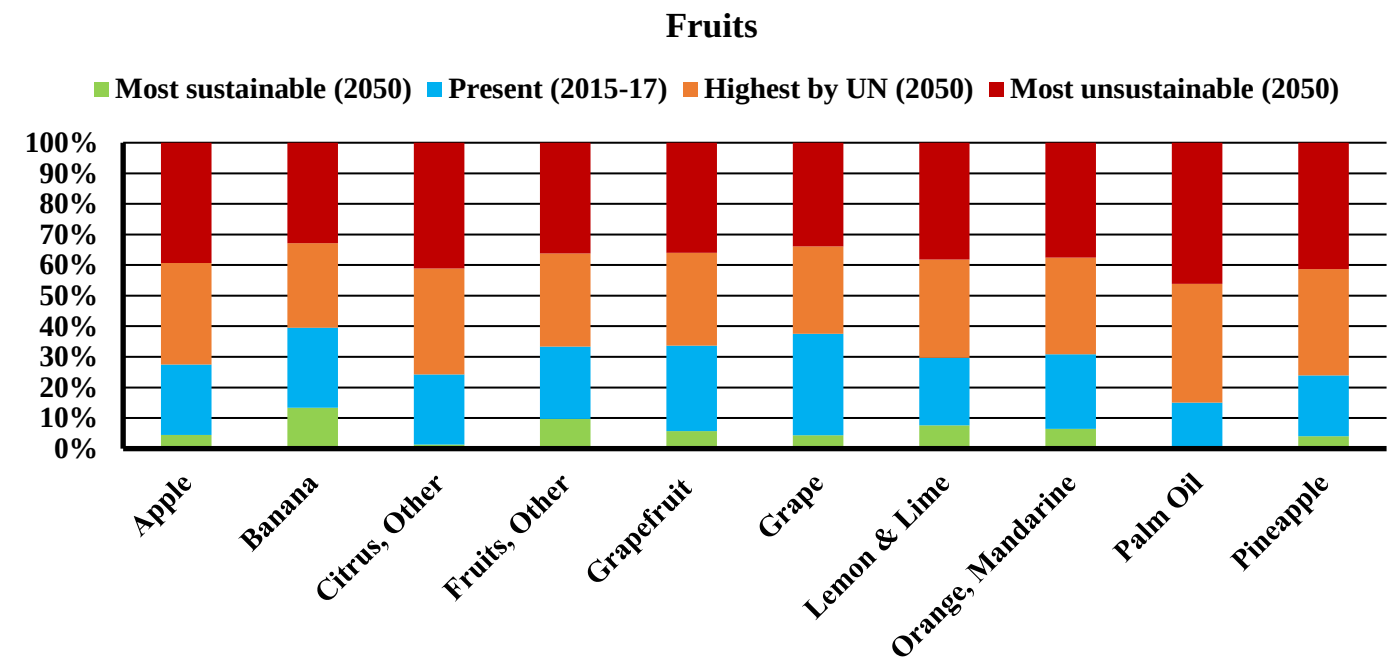


Fig 41: Land gap (2015-17 vs. 2050) in consumption of fruits in India. (Objective 2, 4)

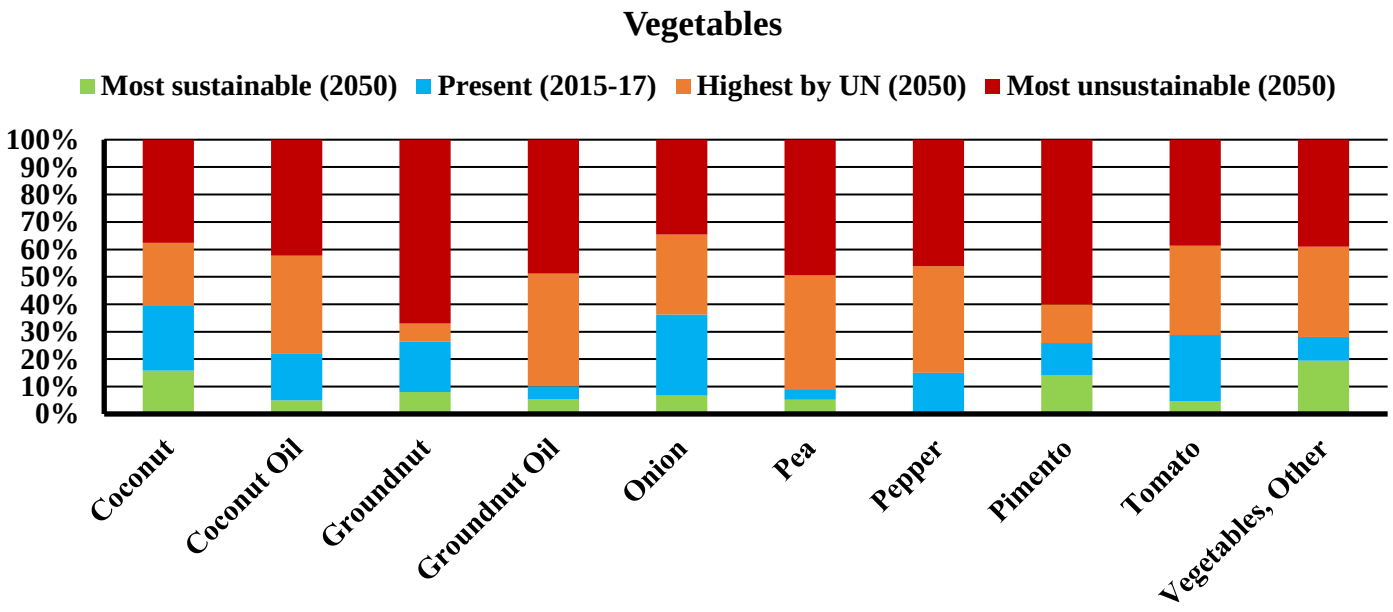


Fig 42: Land gap (2015-17 vs. 2050) in consumption of vegetables in India. (Objective 2, 4)

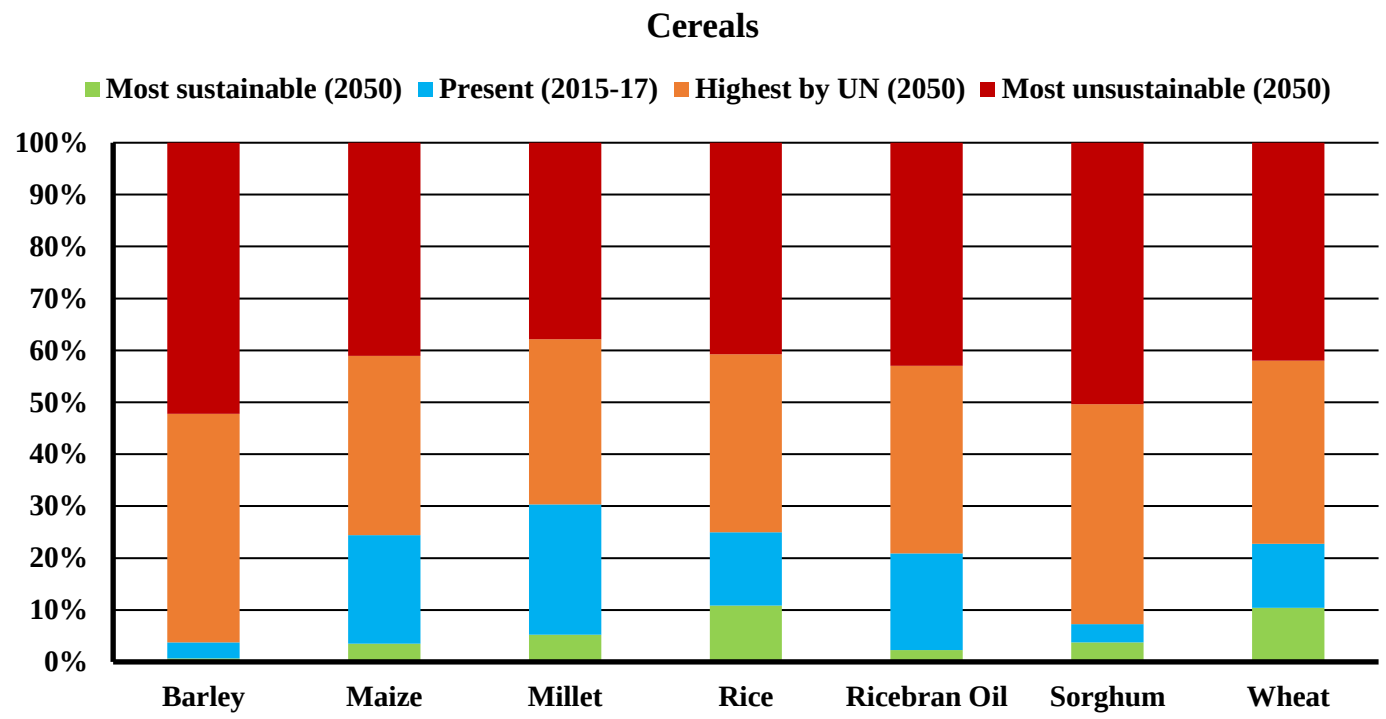


Fig 43: Land gap (2015-17 vs. 2050) in consumption of cereals in India. (Objective 2, 4)

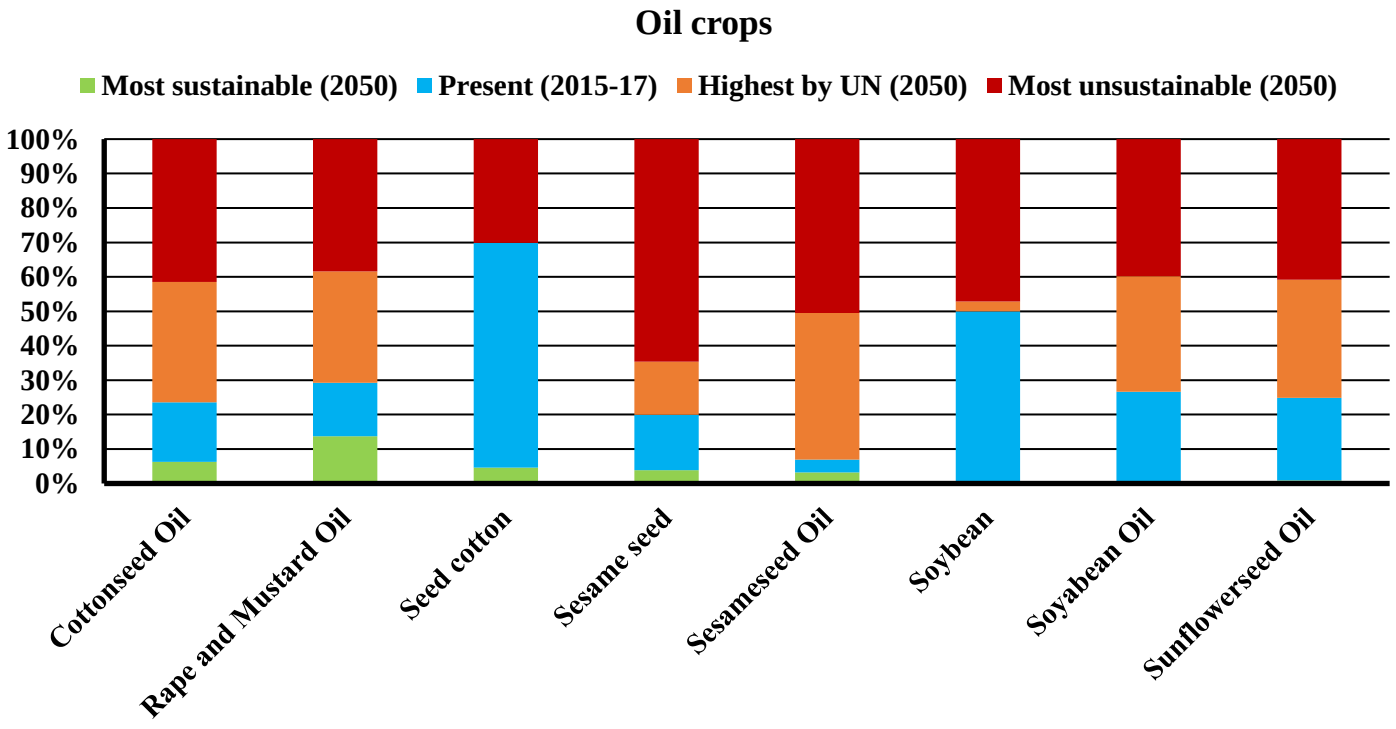


Fig 44: Land gap (2015-17 vs. 2050) in consumption of oil crops in India. (Objective 2, 4)

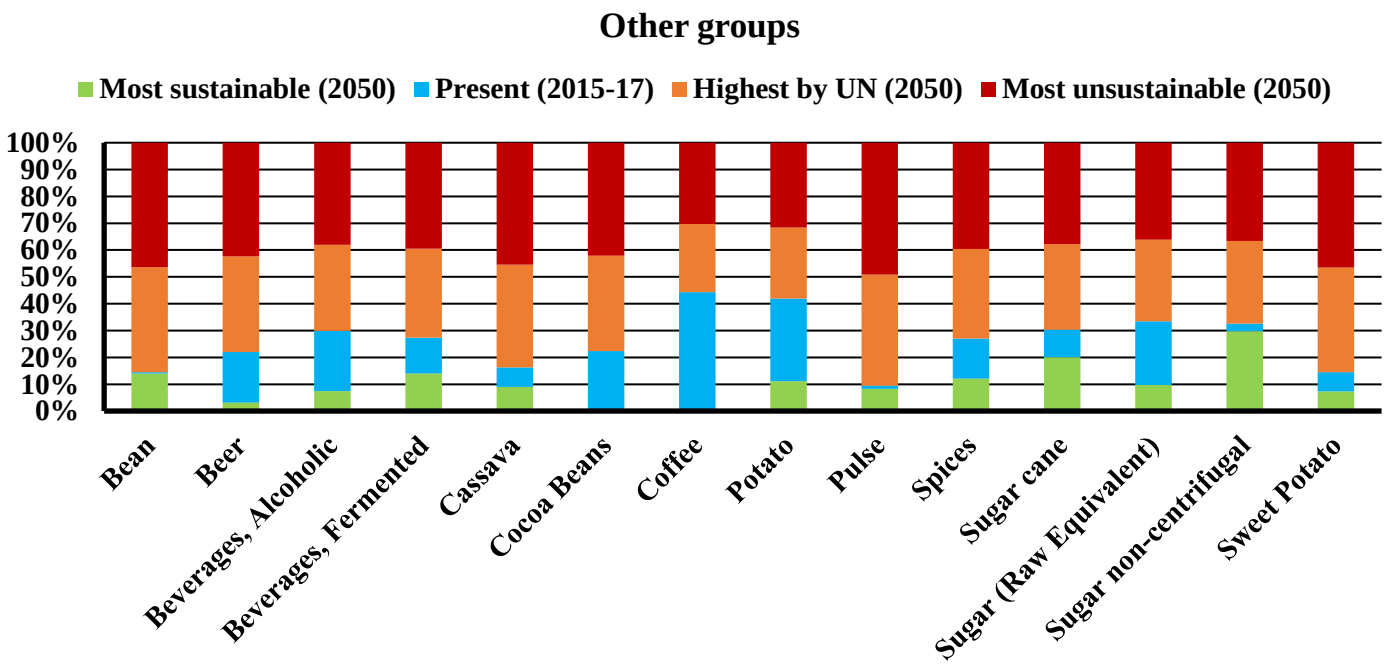


Fig 45: Land gap (2015-17 vs. 2050) in consumption of other food groups in India. (Objective 2, 4)

Discussion:

From these four works, it is evident that, though water resource management in agricultural sector should have been much more scientifically well managed (keeping in mind the economic and social implementation aspects), present scenario is not good. If India has to provide sufficient food (that directly comes from agriculture) in accordance to nutrition and food security principles, in coming decades, the agricultural water sector needs to be reorganized (adaptable with changing dietary patterns of Indian population). This work was only a comprehensive overview of present scenarios in this sector. Further works are necessary that should downscale any analysis from national to local scale, so that, policies could be much more suitable and tailor made with different features of different localities. It is also advised that for more detailed analytical understanding, data, of both biophysical and socioeconomic nature, should be abundant.

Overview of the work:

The target of this PhD work is to understand sustainable development of agriculture sector in India (i.e. national scale), with special emphasis to water resource management. The first chapter, entitled '***Safe and Just Operating Space in India***', deals with sustainability of India. It incorporates both biophysical resource consumption and socioeconomic development perspective. This is the very foundation of this work, as it is the preliminary understanding (i.e. overview) of the level of unsustainability in India. Also, it is directly connected to agriculture too (via climate change, freshwater use, nitrogen use, phosphorus use, ecological footprint etc. indicators). The second chapter, entitled '***Sustainable development of Water & Sanitation (SDG 6) in India***', deals with sustainability of water sector in India, in accordance with sustainable development goals of UN. It also incorporates both biophysical resource consumption and socioeconomic development perspective, especially suitable for water sector only. The third chapter, entitled '***Safe and Just Operating Space of Agriculture in India***', deals with sustainable development of agriculture sector in India in coherence with both PB and DE framework. This too incorporates both biophysical resource consumption and socioeconomic development perspective, especially suitable for agriculture sector only. The fourth chapter, entitled '***Water and Land Gap of Agriculture in India***', deals with water and land requirement of all major food products in India that are generated from agricultural products, as per LRF and WRF frameworks. It also yields a clear picture of gap of land and water requirement for food consumption. All of these 4 chapter entails past trend analysis (past, i.e. 1961 or 1975, based on oldest data available), present scenario (2013, 2015 or 2017, based on most recent data available) and future projection (2050). The future projections include various scenarios too (5 shared socioeconomic pathways and 1 UN population projection). Thus, this PhD work gives a step by step analysis of sustainable development of agriculture, from multiple perspectives, in India, with special significance to water sector, at national scale.

References

1. Vermeulen, S.J., Campbell, B., Ingram, J.S., 2012. Climate Change and Food Systems, ***Annu Rev Environ Resour.*** 37, 195-222. https://doi.org/10.1146/annurev-environ-020411-130608
2. Wollenberg, E., Richards, M., Smith, P., Havlík, P., Obersteiner, M., Tubiello, F.N., Herold, M., Gerber, P., Carter, S., Reisinger, A., van Vuuren, D.P., Dickie, A., Neufeldt, H., Sander, B.O., Wassmann, R., Sommer, R., Amonette, J.E., Falcucci, A., Herrero, M., Opio, C., Roman-Cuesta, R.M., Stehfest, E., Westhoek, H., Ortiz-Monasterio, I., Sapkota, T., Rufino, M.C., Thornton, P.K., Verchot, L., West, P.C., Soussana, J.F., Baedeker, T., Sadler, M., Vermeulen, S., Campbell, B.M., 2016. Reducing emissions from agriculture to meet the 2 °C target. ***Glob. Chang. Biol.*** 22, 3859-3864. https://doi.org/10.1111/gcb.13340
3. Carlson, K.M., Gerber, J.S., Mueller, N.D., Herrero, M., MacDonald, G.K., Brauman, K.A., Havlik, P., O'Connell, C.S., Johnson, J.A., Saatchi, S., West, P.C., 2017. Greenhouse gas emissions intensity of global croplands. ***Nat. Clim. Chang.*** 7, 63-68. https://doi.org/10.1038/nclimate3158
4. Campbell, B.M., Hansen, J., Rioux, J., Stirling, C.M., Twomlow, S., (Lini) Wollenberg, E., 2018. Urgent action to combat climate change and its impacts (SDG 13): transforming agriculture and food systems. ***Curr. Opin. Environ. Sustain.*** 34, 13-20. https://doi.org/10.1016/j.cosust.2018.06.005
5. Destouni, G., Jaramillo, F., Prieto, C., 2013. Hydroclimatic shifts driven by human water use for food and energy production. ***Nat. Clim. Chang.*** 3, 213-217. https://doi.org/10.1038/nclimate1719
6. Zabel, F., Putzenlechner, B., Mauser, W., 2014. Global agricultural land resources - A high resolution suitability evaluation and its perspectives until 2100 under climate change conditions. ***PLoS One.*** 9(12): e114980. https://doi.org/10.1371/journal.pone.0107522
7. Scown, M.W., Winkler, K.J., Nicholas, K.A., 2019. Aligning research with policy and practice for sustainable agricultural land systems in Europe. ***Proc. Natl. Acad. Sci.*** 116 (11), 4911-4916. https://doi.org/10.1073/pnas.1812100116
8. Stehfest, E., van Zeist, W.J., Valin, H., Havlik, P., Popp, A., Kyle, P., Tabeau, A., Mason-D'Croz, D., Hasegawa, T., Bodirsky, B.L., Calvin, K., Doelman, J.C., Fujimori, S., Humpenöder, F., Lotze-Campen, H., van Meijl, H., Wiebe, K., 2019. Key determinants of global land-use projections. ***Nat. Commun.*** 10, 2166. https://doi.org/10.1038/s41467-019-09945-w
9. Galloway, J.N., Townsend, A.R., Erisman, J.W., Bekunda, M., Cai, Z., Freney, J.R., Martinelli, L.A., Seitzinger, S.P., Sutton, M.A., 2008. Transformation of the nitrogen cycle: Recent trends, questions, and potential solutions. ***Science,*** 320 (5878), https://doi.org/10.1126/science.1136674
10. Liu, J., You, L., Amini, M., Obersteiner, M., Herrero, M., Zehnder, A.J.B., Yang, H., 2010. A high-resolution assessment on global nitrogen flows in cropland. ***Proc. Natl. Acad. Sci.*** 107(17), 8035-8040. https://doi.org/10.1073/pnas.0913658107
11. Robertson, G.P., Vitousek, P., 2010. Nitrogen in Agriculture: Balancing the Cost of an Essential Resource. ***Annu Rev Environ Resour.*** 34, 97-125. https://doi.org/10.1146/annurev.environ.032108.105046
12. De Vries, W., Kros, J., Kroeze, C., Seitzinger, S.P., 2013. Assessing planetary and regional nitrogen boundaries related to food security and adverse environmental impacts. ***Curr. Opin. Environ. Sustain.*** 5 (3-4), 392-402. https://doi.org/10.1016/j.cosust.2013.07.004

13. Cordell, D., White, S., 2014. Life's Bottleneck: Sustaining the World's Phosphorus for a Food Secure Future. ***Annu Rev Environ Resour.*** 39, 161-188. https://doi.org/10.1146/annurev-environ-010213-113300
14. Zhang, J., Beusen, A.H.W., Van Apeldoorn, D.F., Mogollón, J.M., Yu, C., Bouwman, A.F., 2017. Spatiotemporal dynamics of soil phosphorus and crop uptake in global cropland during the 20th century. ***Biogeosciences***, 14, 2055-2068. https://doi.org/10.5194/bg-14-2055-2017
15. Newbold, T., Hudson, L.N., Arnell, A.P., Contu, S., De Palma, A., Ferrier, S., Hill, S.L.L., Hoskins, A.J., Lysenko, I., Phillips, H.R.P., Burton, V.J., Chng, C.W.T., Emerson, S., Gao, D., Hale, G.P., Hutton, J., Jung, M., Sanchez-Ortiz, K., Simmons, B.I., Whitmee, S., Zhang, H., Scharlemann, J.P.W., Purvis, A., 2016. Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment. ***Science***, 353 (6296), 288-291. https://doi.org/10.1126/science.aaf2201
16. Mace, G.M., Barrett, M., Burgess, N.D., Cornell, S.E., Freeman, R., Grooten, M., Purvis, A., 2018. Aiming higher to bend the curve of biodiversity loss. ***Nat. Sustain.*** 1, 448-451. https://doi.org/10.1038/s41893-018-0130-0
17. Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F.S., Lambin, E., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sorlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J., 2009. A safe operating space for humanity. ***Nature***, 461, 472-475. doi: 10.1038/461472a
18. Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sörlin, S., 2015. Planetary boundaries: guiding human development on a changing planet. ***Science*** 80:347. doi:10.1126/science.1259855 1259855.
19. O'Neill, D. W., Fanning, A. L., Lamb, W. F., Steinberger, J. K., 2018. A good life for all within planetary boundaries. ***Nat. Sust.*** 1, 88–95. doi: 10.1038/s41893-018-0021-4.
20. Raworth, K., 2017a. A Doughnut for the Anthropocene: humanity's compass in the 21st century. ***Lancet Planet. Health.*** 1 (2), e48–e49. doi: 10.1016/S2542-5196(17)30028-1.
21. Raworth, K., 2017b. Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist (Random House, London).

Databases

- Aquastat, 2018. FAO Statistical Database. (http://www.fao.org/aquastat/en/)
- Emissions Database for Global Atmospheric Research (EDGAR) v4.3.2 (https://edgar.jrc.ec.europa.eu/)
- Food and Agriculture Organization, 2018. FAO Statistical Database. (http://faostat.fao.org/)
- Global Footprint Network, 2019. National Footprint Accounts (GFN, Oakland, California).
- SSP database
- Transparency International, 2018. Corruption perceptions index (https://www.transparency.org/).
- UNU-WIDER, 'World Income Inequality Database (WIID3.4), 2018. (https://www.wider.unu.edu/database/world-income-inequality-database-wiid34)
- WaterStat, 2019 (https://waterfootprint.org/en/resources/waterstat/)
- World Bank *World Development Indicators* (World Bank, 2018); (http://data.worldbank.org/)
- World Health Organization, 2015. World Health Statistics. (WHO, Geneva)
- World Resource Institute, 2019. Climate Analysis Indicators Tool (CAIT) (http://cait.wri.org)
- Worldwide Governance Indicators, 2018 (https://info.worldbank.org/governance/wgi/#home).

Seminars & Conferences

No.	Name	Date	Place	Activity
1	7th India Biodiversity Meet 2019 (International Conference)	19-21st November, 2019	Indian Statistical Institute, Kolkata	Accepted
2	Water Future Conference 2019 (International Conference)	24-27th September, 2019	Divecha Centre for Climate Change, Indian Institute of Science, Bangalore	Accepted in Oral Presentation category
3	6th India Biodiversity Meet 2019 (International Conference)	14-16th February, 2019	Indian Statistical Institute, Kolkata	Oral Presentation
4	Golden Jubilee International Conference on 'Trends in Zoology'	3-4th January, 2019	Department of Zoology, University of Burdwan	Oral Presentation
5	3rd International Conference on the theme Mother Earth: Environmental Crisis & Sustainable Strategies (ICME 2018)	11-13th January, 2018	Department of Environmental Science, University of Burdwan	Oral Presentation (received **'Young Scientist' Award**)
6	UGC-sponsored National Seminar on 'Conservation of Biodiversity and Natural Resources in Sustainable Development'	6-7th September, 2016	Department of Zoology, APC College & Department of Zoology, Bajkul Milani Mahavidyalaya	Poster presentation
7	National Conference on Applied Zoology in Sustainable Development: An Update	30th Jan – 2nd February, 2015	Department of Zoology, University of North Bengal	Oral Presentation
8	International Conference on Environmental Biology and Ecological Modelling (ICEBEM 2014)	24-26th February, 2014	Department of Zoology, Visva-Bharati	Poster presentation

INTERNATIONAL CONFERENCE ON ENVIRONMENTAL BIOLOGY

AND

ECOLOGICAL MODELLING (ICEBEM 2014)

Department of Zoology

(Centre for Advanced Studies)

VISVA-BHARATI, SANTINIKETAN 731235

Certificate

This is to certify that Prof. / Dr. / Mr. / Mrs. / Miss / Ajishnu Roy

participated / presented poster / delivered oral presentation / invited lecture / special lecture / acted as chairperson in the International Conference on on Environmental Biology and Ecological Modelling (ICEBEM 2014) organized by Department of Zoology, Visva-Bharati during 24 - 26 February, 2014.

Prof. V. C. Joy
Jt. Convener

Prof. Santanu Ray
Jt. Convener

National Conference on Applied Zoology in Sustainable Development: An Update

January 30 - February 02, 2015

This Certificate is presented to

Mr. Ajishnu Roy

for participation and for contributing

in this Conference.

T. K. Chaudhuri

Tapas Kumar Chaudhuri
Organizing Secretary
Department of Zoology
University of North Bengal
Siliguri, Darjeeling, West Bengal

UGC-SPONSORED NATIONAL SEMINAR

On

"Conservation of Biodiversity and Natural Resources in Sustainable Development"

ORGANIZED BY:

Department of Zoology, Acharya Prafulla Chandra College, New Barrackpore

In collaboration with

Department of Zoology, Bajkul Milani Mahavidyalaya

Certificate

Prof./ Dr. / Mr. / Ms. Ajishnu Roy ..... of ..... Presidency University ..... Participated / Presented paper / Poster /as an Invited Speaker / Acted as Chairperson in a scientific session in the Seminar held on 06th and 07th of September, 2016.

Dr. Saktibrata Bhowmik
Principal, A.P.C. College &
Chairman, Organizing committee

Dr. Sutapa Biswas
Secretary
Organizing committee

Dr. Nithar Ranjan Madhu
Convener
Organizing committee

THIRD INTERNATIONAL CONFERENCE

ICME-2018

On the Theme

Mother Earth: Environmental Crisis & Sustainable Strategies

Organised by

Department of Environmental Science

THE UNIVERSITY OF BURDWAN

Certificate of Participation

This is to certify that

Ajishnu Roy
(Name of the participant)

(Designation)

Presidency University
(College/University/Institute)

Kolkata, WB
(Place)

Awarded 'Young Scientist' in the ***THIRD INTERNATIONAL CONFERENCE*** *on the Theme:* ***"Mother Earth: Environmental Crisis & Sustainable Strategies"*** *held during January 11 to 13, 2018.*

Purba Bardhaman, West Bengal, India
Date: January 13, 2018

Jt. Conveners
International Conference
Environmental Sc., The University of Burdwan

Jt. Secretaries
International Conference
Environmental Sc., The University of Burdwan

Golden Jubilee International Conference

On

Trends in Zoology

(January 3-4, 2019)

Organized by

Department of Zoology
The University of Burdwan
West Bengal, India

Certificate

This is to certify that Prof. / Dr. / Mr. / Ms. Rishnu Roy ..... *of*
Dept. of Life Sciences, Presidency University, Kolkata .....
chaired a session / delivered invited lecture / presented a paper / participated in the Golden Jubilee International Conference on 'Trends in Zoology' held on January 03-04, 2019, organized by the Department of Zoology, The University of Burdwan, Burdwan, West Bengal, India.

Dr. K. Ghosh & Dr. S. N. Chatterjee	Prof. A. Barik	Prof. G. Chandra	Prof. N. C. Saha
Organizing Secretaries	*Convener*	*President*	*Vice Chancellor*

Certificate of Participation

This is to certify that **Ajishnu Roy**, Presidency University has participated and delivered an oral presentation entitled *"A Global Analysis of Contribution of Agriculture in Planetary Boundaries: Past, Present and The Future"* in the **"6th India Biodiversity Meet 2019 (International Conference)"**, held at Indian Statistical Institute, Kolkata, from 14th - 16th February, 2019.

Abhishek Mukherjee
Organising Secretary

Sabyasachi Bhattacharya
Head, AERU, ISI

6th INDIA BIODIVERSITY MEET 2019
International Conference
14 -16 FEBRUARY, 2019

Publications

1. Roy, A., Pramanick, K., (2019). Analysing progress of sustainable development goal 6 in India: Past, present and future. ***Journal of Environmental Management***, 232, 1049–1065. doi: 10.1016/j.jenvman.2018.11.060
2. 'Safe and just operating space for India' has been accepted for publication as book chapter in ***Handbook of Modern Environmental Materials Management***, Chaudhery Mustansar Hussain (Ed.), Springer (ISBN: 978-3-319-58538-3) under section: *XIV Pollution Prevention, Sustainability and Green world*.
3. 'Review on Water Footprint (WF) of Agriculture: Indian Scenario' has been accepted for publication as book chapter in ***Biodiversity, Conservation and Sustainable Development***, Vol. 2, (New Academic Publishers, New Delhi)
4. Under peer review. (Analysing the safe and just operating space of agriculture in the World: past, present and future)
5. Manuscript under preparation (Analysis of water and land gap in agricultural products for food consumption in India).